The University of Chicago

■

THE STRUCTURAL GEOLOGY AND PHYSIOGRAPHY OF THE TETON PASS AREA, WYOMING

A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE PHYSICAL
SCIENCES IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY AND
PALEONTOLOGY
1938

BY

LELAND HORBERG

Private Edition, Distributed by
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CHICAGO, ILLINOIS

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Number 16, 1938

National Park Service.

TILTED PALEOZOIC BEDS FORMING THE WEST SLOPE OF THE TETON RANGE.

View into Teton Canyon (Alaska Basin) from the saddle at the head of Cascade Canyon. The canyon is floored with Flathead quartzite and pre-Cambrian crystalline rocks, the lower limestone ledges are formed by the Gros Ventre formation, the prominent wall by the Bighorn dolomite and the higher peaks by the Madison-Brazer limestone.

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PREFACE

This study embodies the results of field work carried on by the writer during one month of the summer of 1933 and two months of the summers of 1936 and 1937. During those periods the area about Teton Pass, the east slope of the Snake River Range, most of the west slope of the Teton Range and the buttes in the south part of Jackson Hole were rapidly explored and mapped. In mapping, the Jackson and Grand Teton topographic sheets were used as a base, locations being determined with a pocket transit and altimeter. Emphasis was placed on the relations of the structure of the Snake River Range to that of the Teton Range.

The writer wishes to acknowledge his indebtedness to F. M. Fryxell of Augustana College, Rock Island, Illinois, for arousing an interest in the problem and for constant encouragement and advice. To Professors R. T. Chamberlin and J Harlan Bretz particularly, the writer is grateful for counsel and criticism. Rudolph Edmund has kindly furnished unpublished information on glacial features of the west slope of the Tetons. Two days spent with W. W. Rubey of the U. S. Geological Survey in the field near Afton, Wyoming, helped greatly in the definition of Mesozoic formations. During the summer of 1936 the writer was assisted by Leroy Brissman and in 1937 by Paul Nelson. Photographs have been provided by F. M. Fryxell, Rudoph Edmund, and the National Park Service.

CHAPTER I

Introduction

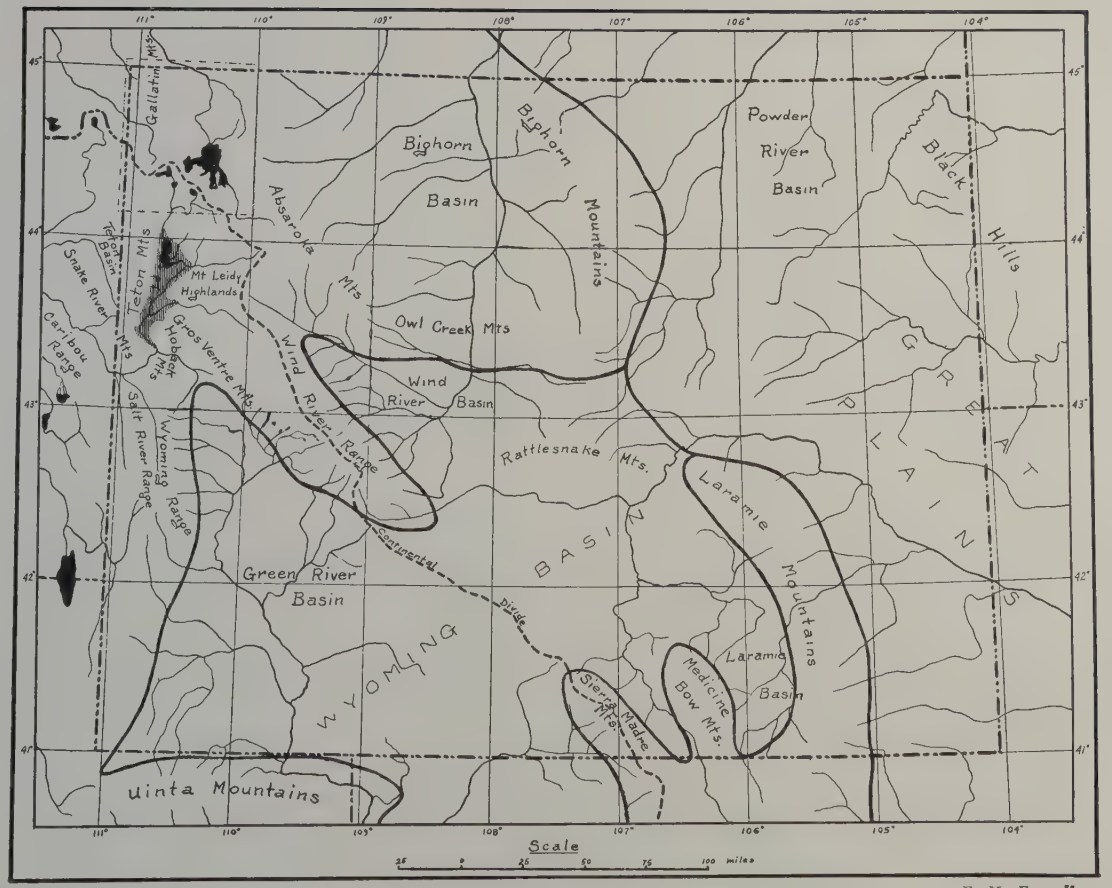
The Teton Pass Area is situated in northwestern Wyoming, about fifty miles south of the southern boundary of Yellowstone National Park, between parallels 43°10′ and 43°50′ north latitude, and between meridians 110°40′ and 111°50′ west longitude (Fig. 1). Centrally located within the Middle Rocky Mountain Province, the area includes parts of Jackson Hole, the Teton Range, the Snake River Range, and the eastern margin of Teton Basin.

PHYSIOGRAPHIC DIVISIONS

Jackson Hole.

Jackson Hole is a narrow intermontane basin extending southward for forty-eight miles from a point eight miles south of the southern boundary of Yellowstone National Park and varying in width from six to twelve miles. Completely surrounded by mountains, it forms one of the most severely enclosed basins in the region (Fig. 2). The floor of the basin ranges in altitude from 6000 to 7000 feet and the adjacent highlands rise to elevations from 8000 to over 13,000 feet. On the north, the basin is separated from the Pitchstone Plateau of Yellowstone National Park by a group of irregular highlands which extend both east and west of the Snake River. The eastern margin is bounded by the Mt. Leidy Highlands and the Gros Ventre Range, the southern end by the Hoback, Wyoming, and Snake River Ranges, and the rugged western boundary is formed by the Teton and Snake River Ranges. Located just west of the Continental Divide, the basin is drained by Snake River and its headwater tributaries, the chief of which are the Buffalo Fork and the Gros Ventre River.

The flat, aggraded floor of Jackson Hole has been but little dissected by streams which are cutting in the Quater-

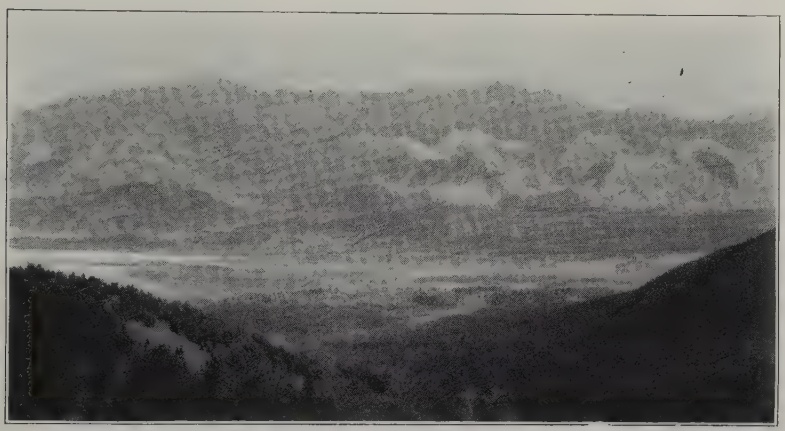


F. M. Fryxell

FIGURE 1.

Index map, showing location of the Teton Pass Area and its relation to the physiographic features of Wyoming.

nary fill, so that glacial outwash plains with features of slight relief comprise large areas. The level surface is broken by buttes, which rise abruptly, 500 to 1300 feet, from the floor of the basin, by glacial moraines that extend along the western and northern margin and enclose the large lakes, and to a less extent by terraces, abandoned stream channels, and alluvial fans. There are four prominent buttes: Signal Mountain near Moran, Blacktail Butte, located near the center of the basin near Moose, and East



National Park Service.

FIGURE 2.

Jackson Hole viewed from Teton Pass. The Gros Ventre Buttes rise from the floor of the basin and the Gros Ventre and Hoback Ranges form its eastern border.

and West Gros Ventre Buttes near Jackson. Associated with the latter group are three smaller, unnamed buttes and similar features are found in the vicinity of Signal Mountain.

Teton Range.

Due to the complete absence of foothills and the unusually precipitous eastern front, this range when viewed from the floor of Jackson Hole presents one of the most impressive mountain fronts in the Cordilleran region (Figs. 3 and 5). Near Jenny Lake the mountain wall rises almost a mile and a half within a horizontal distance of less than three miles.

The rugged line of north-south trending peaks, which have been carved from steeply dipping gneisses, schists, and other rocks, and severely eroded by mountain glaciers, have an aspect of truly alpine character. Structurally the range is a great fault block uplifted and tilted to the west and broken by a number of secondary fractures (Fig. 4). Hence, the uplift is markedly asymmetrical with the main peaks, separated by short, narrow canyons, crowded near the east-

Furnished by National Park Service.

FIGURE 3.

Airplane view of the main Teton peaks from the east. The central peak is the Grand Teton and Teton Glacier lies just to the right of it.

ern margin where they form a crest line which maintains an elevation of over 10,000 feet for a distance of forty miles. The western slope of the range is largely formed of sedimentary beds which dip gently westward and are trenched by a number of long, steep-walled canyons. The most rugged portion of the range, limited to the area of crystalline rocks, culminates southeast of Jenny Lake in a group of peaks which include the Grand Teton (15,766 feet), Mount

Owen (12,922 feet), Middle Teton (12,798 feet) and South Teton (12,505 feet). Essentially this crystalline area is included in Grand Teton National Park.

On the west the boundary between the Teton Range and Teton Basin is marked by the contact between the alluvial fill of the basin and the lava flows which cover the sedimentary beds on the lower portion of the backslope. Northward the flows extend farther into the basin and rise to form the southern extension of the Pitchstone Plateau where the structure of the range becomes completely buried. South of Phillips Canyon the regular outline of the block is broken by faulting and the crest line, as far as the southern boundary at Teton Pass, is displaced to the west. This portion has been termed the Teton Pass Mountains.

The Snake River Range.

At Teton Pass the north-south trending Teton Range gives way to the less well-defined Snake River Range (Fig. 6) which follows a general northwesterly direction. The gap between the two ranges has an elevation of 8431 feet and forms the only route by which Jackson Hole can be entered from the west.[1] Topographically the Snake River Range embraces a series subparallel ridges which have been maturely dissected by streams flowing east into Jackson Hole and southwest into Grand and Swan Valleys. The sinuate divide between these streams ranges in elevation from 8000 to almost 10,000 feet (Observation Peak, 9972 feet). South of Snake River, the western part of the range is continued as the Salt River Range, while the structure lines east of the watershed diverge into the Wyoming Range and Middle

[1] In the history of exploration and settlement of Jackson Hole, Teton Pass holds a prominent position. First used by Indians whose obsidian artifacts may still be found at the pass, it was probably later utilized by John Colter (1807–08), the first white man to visit the region, and by the Astorians (1811–12). During the "Fur Era" the pass was well known to the roving trappers, and to the exploring parties and early settlers entering the region in the last three decades of the nineteenth century, it provided a feasible route into Jackson Hole.

Ridge.[1] To the northwest the mountains merge with the Big Hole Range which forms the western border of Teton Basin.

Teton Basin.

Teton Basin[2] is a V-shaped intermontane basin somewhat similar to Jackson Hole in its fill of alluvial material, but of smaller size and not nearly so rigorously mountain-locked. The eastern side is bounded by the Tetons and the southern and western sides by the Snake River and Big Hole ranges; to the north it opens out into the broad lava-floored Snake River Plains. The basin, which is about thirty miles long and from five to ten miles wide, is drained by the Teton River and its tributaries.

PREVIOUS WORK AND LITERATURE

The geologic literature on the Teton Pass Area and the region immediately adjoining it includes a number of titles bearing incidentally, and a few directly, on structural and physiographic problems.[3] In 1872 the first of the Hayden Survey parties entered the region and the general geological relations were described by Frank H. Bradley.[4]. The second of these parties arrived five years later and the essential structural features were clearly set forth by Orestes St. John.[5]

---

[1] This usage follows the geographic names shown on the Jackson Quadrangle topographic sheet (1932), and departs from the views of Schultz who considered the northward extension of the Wyoming Range as the southern part of the Big Hole Range. According to Schultz the boundary between the Snake River and Salt River ranges and the Wyoming and Big Hole ranges follows the depression along Greys River valley and the headwaters of Elk and Indian creeks. A. R. Schultz, "A Geologic Reconnaissance for Phosphate and Coal in Southwestern Idaho and Western Wyoming," *U. S. Geol. Survey, Bull. 680* (1918), pp. 35–37.

[2] Formerly known as Pierres Basin or Hole.

[3] See bibliography.

[4] Frank H. Bradley, "Explorations of 1872: U. S. Geological Survey of the Territories, under Dr. F. V. Hayden; Snake River Division," *Amer. Jour. Sci.*, 3d series, Vol. VI (1873), pp. 194–207.
Frank H. Bradley, "Geological Report of the Snake River Division," *Sixth Annual Report of the U. S. Geol. Surveys of the Territories* (Washington, 1873), pp. 191–271.

[5] Orestes St. John, "Geological Report of the Teton Division," *Eleventh Annual Report of the Geological Survey of the Territories* (Washington, 1879), pp. 321–508.

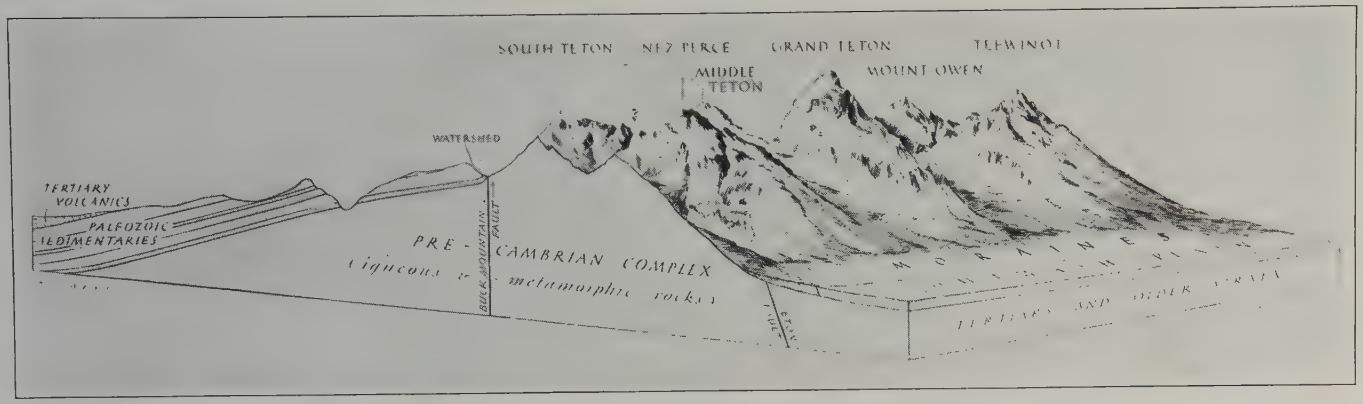


FIGURE 4.
Block diagram of the Teton Range.

FIGURE 5.
Teton Range from the floor of Jackson Hole.

Copyright W. O. Owen.

More recently interest in coal and phosphate reserves prompted the U. S. Geological Survey to send reconnaissance parties into parts of the area during the years 1910–1912. At this time the structural trends and stratigraphic units were more clearly defined and certain areas containing promising deposits were studied in detail. A part of the Snake River Range was studied by A. R. Schultz and the west slope of the Teton Range and the buttes in Jack-

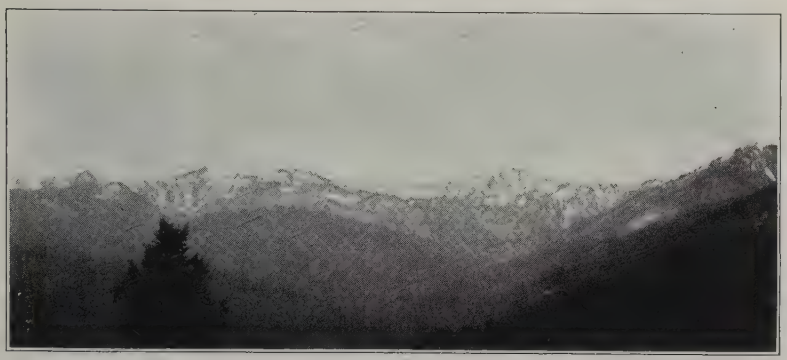


FIGURE 6.
Snake River Range near the head of Coburn Creek.

son Hole were examined by Eliot Blackwelder. The more important results of these investigations are incorporated in publications of the U. S. Geological Survey dealing with economic geology, and also in papers by Blackwelder on physiography and stratigraphy.[1]

The interesting glacial features of Jackson Hole have been studied in detail by F. M. Fryxell and the same author has described the existing glaciers within the Teton Range.[2]

[1] A. R. Schultz, "A Geologic Reconnaissance for Phosphate and Coal in Southeastern Idaho and Western Wyoming," *U. S. Geol. Survey Bull. 680* (1918), pp. 1–84.

Eliot Blackwelder, "A Reconnaissance of the Phosphate Deposits in Wyoming," *U. S. Geol. Survey Bull. 470* (1911), pp. 452–483; "Post-Cretaceous History of the Mountains of Central Western Wyoming," *Jour. Geol.*, Vol. XIII (1915), pp. 97–117, 193–217, 307–340; "New Geological Formations in Western Wyoming," *Jour. Wash. Acad. Sci.*, Vol. VIII (1918), pp. 417–426.

[2] F. M. Fryxell, "Glacial Features of Jackson Hole, Wyoming," *Augustana Library Publ.* 13 (1930), 129 pp.; "Glaciers of Grand Teton National Park of Wyoming," *Jour. Geol.*, Vol. XLIII (1935), pp. 381–397.

CHAPTER II

Stratigraphy

The stratigraphic units of the area are shown in the table below (Table 1). The formational names adopted represent a compromise between units previously described by workers in northwestern Wyoming, southwestern Wyoming and southeastern Idaho. In general the Paleozoic section corresponds closely to that of the Yellowstone Region, while the Mesozoic sequence is similar to that in the areas to the south and west. Both Paleozoic and Mesozoic beds become thicker to the southwest as Mansfield's area in southeastern Idaho is approached (Fig. 11).[1]

The thicknesses of pre-Pennsylvanian formations have been determined by the writer and other geologists interested in stratigraphic problems in the area. Accurate figures for the younger formations are not available, because structural complications and scarcity of well-exposed sections have made measurements impossible.

PRE-CAMBRIAN

The pre-Cambrian rocks forming the nucleus of the Teton Range were examined only incidentally during the mapping of the sedimentary formations, and although their areal extent is well known, the details of petrology and structure await further investigation. Along the east slope of the range outcrops are known from Berry Creek[2] on the north as far south as Teton Pass, and for over twenty miles northward from Death Canyon they form the crest of the most rugged portion of the mountains. Near the head of Moran Canyon the crystalline axis branches into two salients which continue northward and northwestward until both disappear beneath the volcanics.

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[1] G. R. Mansfield, "Geography, Geology, and Mineral Resources of of Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152*, 1927, pp. 1–447.

[2] Shoshone Quadrangle.

TABLE 1

GEOLOGIC COLUMN, TETON PASS AREA

Age	*Formation*	*Thickness*	*Character*
Recent	Alluvium	.....	Includes floodplain and piedmont deposits
Pleistocene	Pinedale till	.....	Youthful, undissected moraines and outwash plains
	Bull Lake till and outwash	.....	Submaturely eroded moraines and outwash plains commonly loess-covered; outwash often occurs as terraces
	Buffalo till	.....	Till remnants found on mountain slopes, ridges and buttes; 400–1200 feet above present drainage
Eocene–Miocene (?)	Unconformity Volcanics	.....	Rhyolite and andesite flows, breccia and tuff of variable age; in places interbedded with sediments
Eocene–oligocene (?)	Undifferentiated sediments	.....	White to buff clays, tuffaceous sandstone, and fresh water limestone; contains local lava flows
Eocene	Pinyon (Almy) Conglomerate	+[1] 500—	Coarse conglomerate with interbedded sand and sandy clay
Upper Cretaceous	Unconformity Frontier Formation	+[1] 3000—	Gray and buff shales and sandstones with coal beds
	Aspen Formation	+[1] 1000—	Gray and black shales, shaly sandstone, massive gray sandstone, and coal beds. Speckled, gray-green porcellanite occurs in the sandstones [2]
	Bear River Formation	+[1] 800—	Black, carbonaceous shale, ferruginous sandstone, gray limestone and impure coal beds. Invertebrate fossils are abundant in the shale and in places form a white coquina. Dark minerals present in the sandstone
Lower Cretaceous	Unconformity (?) Gannett Group	+[3] 250—	Red shales and sandstone, conglomerate, and dense flinty limestone. Freshwater gastropods occur in the limestone
Jurassic	Unconformity (?) Stump Formation	+[3] 75—	Grayish-green, calcareous sandstone which is fine grained, thin-bedded and weathers brown
	Preuss Formation (?)	+[3] 50—	White to pink sandstone and red shale; thin and poorly exposed
	Unconformity (?) Twin Creek Limestone	+[3] 350—	Dense, gray limestone and buff to gray shaly limestone which weathers into splintery fragments. Fossils are abundant
	Unconformity Nugget Sandstone	+[3] 100—	Buff to red, fine-grained quartzitic sandstone

TABLE 1—*Continued*

Age	*Formation*	*Thickness*	*Character*
Triassic	Unconformity (?) Ankareh Shale	+[3] 100—	Brownish-red shale and shaly sandstone with interbedded dense, gray limestone
	Unconformity Dinwoody Formation	+[3] 250—	Thin-bedded, gray, calcareous sandstone which weathers with a brown-stained surface, calcareous shale and massive fossiliferous limestone of the Thaynes type. Pelecypods are common in the limestone
Permian	Phosphoria Formation	50–150[3]	Cherty limestone (Rex Chert member) at top, overlying brown sandstone, black shale and phosphorite. The phosphorite is commonly oölitic
Pennsylvanian	Wells Formation	+[3] 300—	White to pink quartzite, massive, gray limestone, and red, calcareous shale. Fossils are abundant in the limestone
Mississippian	Unconformity Madison–Brazer Limestone	850—[3] 1000	Blue-gray, dense limestone which are thin-bedded in part, but dominantly massive; buff, shaly limestone with red banding. Black chert nodules common in the upper (Brazer) portion. Abundant fossils at many horizons
Devonian	Darby Formation	150—[3] 250	Brownish-gray, massive dolomites containing iron sulphides with interbedded, variegated shales. Fossils sparingly present
Ordovician	Unconformity Bighorn Dolomite	340–[4] 385	Massive, light gray to cream colored dolomite with rough pitted surface. About 40 feet of dense, brittle dolomite at the top forms the Leigh member. Fossils rare. The formation is an important cliff-former
Upper Cambrian	Unconformity Gallatin Limestone	180–[4] 220	Bluish-gray, mottled limestone which is oölitic in places and weathers with pitted surfaces. Fossils are rare
Cambrian	Unconformity Gros Ventre Formation	+[4] 600—	Fine-grained, dark gray limestone with beds of oölite and flat-pebble conglomerate interbedded with green, micaceous shale. Fossils are numerous at certain horizons
Middle Cambrian	Flathead Quartzite	175[4]	White to pink quartzite with oölitic hematite, ferruginous and glauconitic sandstone and shale in the upper portion. There is a well-developed basal conglomerate. Fossils rare
Pre-Cambrian	Unconformity	.....	Gneiss and schist intruded by pegmatite and granite and cut by basic dikes

[1] A. R. Schultz, "A Geologic Reconnaissance for Phosphate and Coal in Southeastern Idaho and Western Wyoming," *U. S. Geol. Survey Bull. 680*, 1918, pp. 12–30.
[2] W. W. Rubey, personal communication.
[3] Approximate thicknesses based on measurements made by the writer.
[4] Based in part on measurements made by B. Maxwell Miller. B. Maxwell Miller, "Cambrian Stratigraphy of Northwestern Wyoming," *Jour. Geol.*, Vol. XLIV (1936), pp. 113–144.

The main body of the pre-Cambrian is made up of steeply dipping gneisses and schists which have been intruded by pegmatite, granite and basic dikes, probably in the order named. The basic dikes, which strike east-west across the trend of the range, are conspicuous features of some of the major peaks, notably Mount Moran, Middle Teton and Grand Teton. Departures from the prevailing gneissic and schistose lithology are not common, but do occur as evidenced by the coarse conglomerate at the head of South Avalanche Canyon and by quartzites[1] in scattered localities.

PALEOZOIC

Cambrian.

Throughout the Teton Range the Cambrian is well exposed above the crystalline rocks and in the central portion the contact between the two closely follows the divide (Frontispiece). In the northern and southern portions, where there has been more faulting and folding, the outcrops are scattered and discontinuous.

Included within the system are 950 to 1000 feet of strata representing the Flathead, Gros Ventre, and Gallatin formations. The Flathead and most, if not all, of the Gros Ventre is of Albertan age, while the Gallatin is considered Croixan.[2] In general the section is similar to that in the Gros Ventre, Wind River, and Owl Creek ranges and the area north of Yellowstone Park. Eastward the formations become more clastic and pass into the "Deadwood" formation of eastern Wyoming and to the southwest they thicken rapidly into geosynclinal facies. The Flathead formation consists of two divisions, a lower part containing conglomerate, quartzite and sandstone (140 feet) and an upper division made up of ferruginous sandstone, oölitic hematite, and green, sandy shale (35 feet). The unconformity at the base is marked by an undulatory surface of low relief overlain by a thin conglomerate. There is no perceptible stratigraphic break at the top, the base of the lowest thick shales being taken as the boundary with the Gros Ventre formation. The Gros Ventre includes an upper and lower shale

[1] F. M. Fryxell, personal communication.

[2] B. Maxwell Miller, "The Cambrian Stratigraphy of Northwestern Wyoming," *Jour. Geol.*, Vol. XLIV (1936), pp. 139–143.

division, 220 and 100 feet thick respectively, and a massive, intervening limestone, the Death Canyon member.[1] Horizons of intraformational breccia ("flat-pebble conglomerate"), pebbly limestone, and algae reefs with individual colonies two to three feet in diameter[2] are features characteristic of the upper division. The Gallatin overlies the Gros Ventre unconformably and forms a compact unit of massive, gray limestone (180 feet).

Ordovician.

The Bighorn dolomite overlies the Gallatin unconformably and typically forms prominent white cliffs which are readily identified, even from a considerable distance (Frontispiece). In the Teton Range two distinct members, separated by an unconformity, are recognized: the well-known, massive cream-colored dolomite, which makes up the bulk of the formation (300 feet approx.) and the Leigh member (30–40 feet). The age of the Bighorn cannot be considered definitely established as its fauna has both Trenton and Richmond affinities.[3] Correlatives are the Fish Haven dolomite of southeastern Idaho and the Whitewood formation of the Black Hills. The Leigh member was first recognized by Blackwelder who described it as follows:

> The Leigh member differs from the rest of the Bighorn in being characterized by thin, dense and brittle, flaggy strata with smooth milk-white surfaces. It is stated verbally by Kirk and Tomlinson that, to the southwest in the Bear River Range of Utah and to the northeast in the Bighorn Range of Wyoming, the thin milk-white dolomites are interbedded with the very massive rough weathering strata typical of the Bighorn. Nevertheless it seems possible that correlations with the Leigh may be made in some districts outside of western Wyoming, where it is typically developed.

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[1] The type section is the divide between Death Canyon and Teton Canyon in the Teton Range. *Ibid.*, p. 119.

[2] Eliot Blackwelder, "A Fully Exposed Reef of Calcareous Algae (?) in the Middle Cambrian of the Teton Mountains," *Amer. Jour. Sci.*, 4th Series, Vol. XXXIX (1915), pp. 646–650.

[3] A. K. Miller, "The Age and Correlation of the Bighorn Formation of Northwestern U. S.," *Amer. Jour. Sci.*, 5th Series, Vol. XX (1930), pp. 195–213.

G. Marshall Kay, "Ordovician Stewartville-Dubuque Problems," *Jour. Geol.*, Vol. XLIII (1935), pp. 586–590.

Although the dolomite generally seems to be barren of organic remains, a characteristic fauna, consisting largely of ostracods with some pelecypods and gastropods, has been found at several localities. This fauna is assigned by Ulrich and Kirk to the Richmond horizon of the late Ordovician. The member takes its name from Leigh Canyon, on the west slope of the Teton Range, for on the south side of that valley there are excellent exposures of the dolomite in its typical condition.[1]

Although generally considered Ordovician, certain features of the Leigh suggest Silurian age. A small fauna collected by Blackwelder in the Gros Ventre Range from beds just below the Leigh was referred to the Niagaran by Weller and Kindle[2] and lithologically the Leigh is similar to the Silurian Laketown dolomite of southeastern Idaho. Near the head of Granite Canyon in the Teton Range lithographic stone of the Leigh type is interbedded with reef limestones, averaging six feet thick, in which *Halysites* and corals of the Cyathophyllid type are most conspicuous.

Devonian.

The Darby formation (250 feet) is usually poorly exposed and typically forms covered slopes between the more resistant Bighorn and Madison (Frontispiece). It was first described by Blackwelder, who states:

The introduction of this new term is made necessary because none in present use fits the stratigraphy of western Wyoming. In the Threeforks section Peale gave the name Threeforks shale to the upper division of the Devonian, but included the lower dolomites which are also Devonian, in his Jefferson limestone. Hague, Weed and others in the Yellowstone National Park later misused the term Threeforks to include also the thin-bedded, dark-colored dolomite of the upper part of Peale's Jefferson, thus limiting the latter term to the very massive beds of gray dolomite below. The Darby formation is apparently equivalent to Peale's Threeforks shale plus the upper part of his Jefferson limestone. The formation rests discon-

[1] Eliot Blackwelder, "New Geological Formations in Western Wyoming," *op. cit.*, pp. 419–420.

[2] Eliot Blackwelder, "Origin of the Bighorn Dolomite of Wyoming," "*Bull. Geol. Soc. Amer.*, Vol. XXIV (1913), p. 610.

C. W. Tomlinson, "The Middle Paleozooic Stratigraphy of the Central Rocky Mountain Region," III, *Jour. Geol.*, Vol. XXV (1917), p. 376.

formably on the Leigh dolomite member of the Bighorn, or in some places on the massive member and is separated from the overlying Madison limestone locally, if not generally, by another eroded surface. Lithologically it consists of a varied sequence of shales and dolomites in many colors from white to gray, green, lavender, buff, red, brown and black. Somber colors predominate. Fossils are rare, but have been found at several localities. They indicate Devonian age, but permit no greater refinement in determination. The name is derived from the canyon of Darby Creek, on the west slope of the Teton Range, where the formation is well exposed.[1]

Mississippian.

The Madison-Brazer limestone, because of its thickness (average 900 feet) and resistance to erosion, is the most conspicuous of the Paleozoic formations. On the west slope of the Teton Range the tabular interstream areas and most of the important sedimentary peaks (Mt. Hunt, 10,775 feet, Rendezvous Peak, 10,924 feet, and Fossil Mt., 10,553 feet) are formed of these limestones (Frontispiece). Although both Madison and Brazer are represented in the area, the boundary between the two is not clearly defined and since they combine to form a convenient unit, the hyphenated term has been used in this report. The Madison is typically developed north of Yellowstone Park and is considered lower Mississippian, while the Brazer, which is most fully developed in the region to the southwest, is upper Mississippian. Differences in lithology and fauna serve to distinguish the two formations. The Madison is more thin-bedded and less cherty than the massive Brazer. Numerous small cup corals associated with high and low-spired gastropods and spiriferoid brachiopods differentiates the Madison fauna from the Brazer in which unusually large cup corals and compound corals of the *Lithostrotion* type are distinctive features.[2]

Pennsylvanian.

The Wells formation occurs discontinuously at the north end of the Teton Range and in the vicinity of Teton Pass;

[1] Eliot Blackwelder, "New Geological Formations in Western Wyoming," *op. cit.*, pp. 420–422.

[2] G. R. Mansfield, *op. cit.*, pp. 60–71. Includes a section on Mississippian faunas by G. H. Girty.

on the west slope of the range it is the youngest well-exposed formation uncovered by stripping back of the volcanic flows. Although the general stratigraphy of the Pennsylvanian formations in western Wyoming is quite well known, the exact relations of these formations are uncertain. In this report the name Wells is used to include all strata between the Brazer and the dark, phosphatic shales of the Phosphoria formation. It is thus equivalent to the Quadrant formation as originally described by Weed and to the Amsden and Tensleep formations farther east in Wyoming.[1] Most of the formation is undoubtedly Pennsylvanian, but it may also include some Mississippian strata as the lower portion of the Amsden, the Sacajawea member, has been found to be of that age.[2] In the Teton Pass area the Wells is about 300 feet thick and rests unconformably upon the Brazer. There is considerable variation in thickness and lithology. So far as could be determined from the exposures available, four divisions are present: a thin, lower sequence of sandstone, red calcareous shale and some limestone; a conspicuous quartzitic sandstone, the Dorwin sandstone member of the Amsden formation;[3] a unit of cherty, purple to gray limestones resembling the Brazer; and an upper division of quartzitic sandstone. The latter member was recognized in the vicinity of Teton Pass and on the Gros Ventre buttes where the structure is complicated by faulting. If this member is in its normal position it is probably to be correlated with the Tensleep sandstone occurring just to the east.

Permian.

The Phosphoria formation is known to occur at several points within the area: at Counts Flat on Snake River, in the vicinity of Teton Pass, on the Gros Ventre Buttes, and on the lower backslope of the Teton Range south of Teton Canyon. The formation is usually covered and generally

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[1] D. Dale Condit, "Relations of Late Paleozoic and Early Mesozoic Formations of Southwestern Montana and Adjacent Parts of Wyoming," *U. S. Geol. Survey Prof. Paper 120F*, 1918, pp. 111–112.

[2] C. C. Branson, "Carboniferous Stratigraphy of Wyoming," *Geol. Soc. Amer. Pro.* for 1935, 1936, pp. 391–392.

[3] Blackwelder, *op. cit.*, p. 422–23.

recognized by its black shales or by phosphorite float. It varies considerably in thickness and is seemingly thicker in the southern part of the area than farther north. Although Blackwelder measured over 200 feet of phosphate beds near Counts Flat,[1] farther north the formation can hardly be half so thick. In adjacent areas to the southeast the formation is well developed and consists of a lower division of phosphatic shales and an upper cherty, limestone, the Rex chert member. Traced eastward the formation becomes the lower part of the Embar formation, and in the Yellowstone region it was originally included in the Teton formation and later in the Quadrant.[2]

MESOZOIC

Triassic.

Beds of Triassic age, here referred to the Dinwoody and Ankareh formations, are poorly exposed and are limited in their occurrence to the folded and faulted areas around Teton Pass and south of Munger Mountain. In the Yellowstone region the beds between the top of the Quadrant and the base of the Ellis (Sundance) were referred to the Teton formation,[3] which thus came to represent in part the Park City, Dinwoody, and Chugwater formations of Wyoming, and the Phosphoria, Woodside, Thaynes and Ankareh of Idaho. Condit gives the present status of the term as follows:

> Exclusion from the Teton of the basal portion, equivalent to the Phosphoria formation, leaves the higher shaly brown limestone and red beds of Triassic age to which the name Teton could be applied, but this seems inadvisable for several reasons, one of which is that the name has not been used for regions outside of Yellowstone Park. It is therefore believed that the use of the name Teton will be discontinued when enough additional field work shall have been done both in Montana and southeastern Idaho to permit the proper application of formation names now in use in Idaho and Wyoming.[4]

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[1] Eliot Blackwelder, "A Reconnaissance of Phosphate Deposits in Western Wyoming," *U. S. Geol. Survey Bull 470*, 1911, pp. 462–463.

[2] Condit, *op. cit.*, pp. 112–13.

[3] W. H. Weed, "The Livingston Folio," *U. S. Geol. Survey Geol. Atlas*, No. I, 1894.

[4] Condit, *op. cit.*. p. 114.

In the present study the use of the term Teton was not found desirable, because no difficulty was found in differentiating the Ankareh from the Dinwoody, which is here clearly equivalent to the Thaynes and Woodside formations. The brown, calcareous sandstones characteristic of the Woodside farther south and the dense fossiliferous limestones of the Thaynes are present with typical lithology, but greatly reduced in thickness. The Dinwoody was named by Blackwelder who described its relations as follows:

> The upper part of Darton's Embar formation consists in this region of greenish, gray shales, with many thin plates of calcareous sandstone, or argillaceous dolomite, which weathers brown, tawny and even black (Dinwoody). This portion—which is to be distinguished from the lower or Park City portion of the Embar—is 250 feet thick at Dinwoody Canyon on the north slope of the Wind River Range, but thins down to less than 50 feet near Landor. Mr. D. Dale Condit has traced it into the Bighorn Range, where it merges with the lower part of the Chugwater red beds. Westward it becomes progressively thicker, more calcareous and more fossiliferous and changes by imperceptible gradations horizontally into the Woodside and Thaynes formations of southeastern Idaho. . . . The Dinwoody is conformable both above and below. . . . The name is derived from the canyon of Dinwoody Lakes in the Wind River Range, where the formation is completely exposed and has been measured in detail.[1]

The Dinwoody formation is about 250 feet thick in the area and the overlying Ankareh forms a clearly recognizable unit of red beds, about 100 feet thick. In contrast to the Dinwoody, which is here largely marine, the Ankareh is entirely composed of continental deposits considered time equivalents of the marine Higham, Deadman, and Wood formations (Upper and Middle [?] Triassic) of southeastern Idaho.[2]

Jurassic.

Jurassic formations are exposed in the vicinity of Teton Pass, especially on the north slope of the valley of Mosquito

[1] Eliot Blackwelder, "New Geological Formations in Western Wyoming," *op. cit.*, pp. 425–26.

[2] Mansfield, *op. cit.*, p. 374.

Creek, and in the area south of Munger Mountain. With the exception of the Preuss formation, which is thin and poorly exposed, the units within the Jurassic are clearly defined. The Nugget, being uniformly of quartzitic sandstone (100 feet), is often a ridge-former, and is readily distinguished from the massive limestone ledges and shaley slopes in the Twin Creek. Three units may be recognized in the Twin Creek: a prominent lower limestone (200 feet), a middle shaley limestone member which weathers into slopes covered with splintery, gray limestone fragments (100 feet approx.), and an upper massive limestone usually less than 50 feet thick. Fossils are abundant in all three divisions. The Preuss formation, if present in the area, is represented by about 50 feet of reddish sandstone and shale overlying the Twin Creek and below the typical grayish-green, calcareous sandstones of the Stump (75 feet.) All of the formations are notably thinner than their equivalents to the south and southwest, Mansfield's Jurassic section in southeastern Idaho being over 6000 feet thick.[1] The Nugget wedges out to the north and east, but to the south becomes progressively thicker. It is a continental deposit of late or middle Jurassic age and probably the equivalent of the White Cliff and Vermillion Cliff groups of the Unita Range. The Twin Creek is a marine limestone, largely Upper Jurassic, but including beds in the lower part which may be Middle Jurassic. The Stump and the Preuss are Upper Jurassic, the latter representing a brief interlude of continental deposition prior to the final marine invasion when the Stump was deposited. In a general way the Stump and Twin Creek may be correlated with the Ellis and Sundance formations of northern Wyoming and Montana.[2]

Prior to these marine invasions there was an important period of base-leveling which in southwestern Montana produced an erosion surface truncating beds ranging in age from Carboniferous to Triassic. Condit has suggested that in areas to the south this erosion may have furnished the material for deposits occurring between the Thaynes and Twin Creek.[3] In southern Wyoming the Preuss and Stump

[1] Mansfield, *op. cit.*, p. 49. [2] *Ibid.*, p. 375.
[3] Condit, *op. cit.*, pp. 120–121.

formations have been included in the lower part of the Beckwith.

Cretaceous.

The area south of Teton Pass and east of the divide of the Snake River Range is almost entirely underlain by Cretaceous beds. For the most part these belong to the Bear River, Aspen and Frontier formations, but members of the Gannett group were noted in the vicinity of Munger Mountain and on both sides of the valley of Mosquito Creek. West of Teton Pass the Cretaceous occurs just north of Teton River near the Idaho-Wyoming line. In southeastern Idaho, Mansfield has divided the Gannett group into five formations which are, from top to bottom: the Tygee sandstone, Draney limestone, Bechler conglomerate, Peterson limestone and Ephraim conglomerate.[1]

The beds exposed between the Stump sandstone and the Bear River formation in the Teton Pass area include sandstones, red beds, conglomerates and limestones which have a thickness of about 250 feet and are referred to the Gannett group. Coarse conglomerate of the Ephraim type and limestone similar to that of the Peterson and Draney were recognized, although the formational names are not applicable. In southeastern Idaho the Gannett group has a thickness of over 3200 feet, but in the Big Hole Range less than 1300 feet are exposed.[2] This would indicate rapid thickening of these beds to the southwest. Overlying the Gannett beds in the Teton Pass area is a thick series of Cretaceous sediments in which the Bear River and Aspen formations were recognized, although no attempt was made to differentiate them in mapping. It is probable that the Frontier formation is also present. The relations of the Wayan formation, reported by Mansfield as present in the Bighole Range,[3] to the Cretaceous to the east is not known. The Gannett group is considered to be of early Cretaceous age and Bear River, Aspen and Frontier are late Cretaceous.

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[1] Mansfield, *op. cit.*, p. 49.

[2] *Ibid.*, p. 376.

[3] G. R. Mansfield, "Coal in Eastern Idaho," *U. S. Geol. Survey Bull. 716, Contributions to Economic Geology for 1920* (1921), p. 129.

Pinyon (Almy) Conglomerate.

This deposit is well-exposed along the west slope of the Hoback Range north of Hoback Canyon and what probably represent remnants of the same material were found capping ridges of Cretaceous sandstone in the vicinity of Fall Creek (Fig. 10). The conglomerate is made up of locally derived Paleozoic and Mesozoic rocks, well-rounded and ranging in size from sand and silt to cobbles over a foot in diameter. The fact that no volcanic material is included strongly suggests that it represents the oldest Eocene deposit in the area and is pre-volcanic in age. The deposits of the Hoback Range have been referred to the Almy formation by Schultz and to the Pinyon by Blackwelder.[1]

Tertiary Volcanics.

Volcanic flows and associated tuffs and breccias occur on the lower backslope of the Teton Range, on the Gros Ventre buttes, and north and south of Teton Pass scattered exposures were found at elevations up to 9000 feet. At the north end of the Teton Range the older structures are completely buried by volcanic materials which extend unbroken from Teton Basin into the north end of Jackson Hole. The lithology varies considerably from place to place, although within the area mapped the composition is dominantly andesitic. The flows of the Teton Range are fine-grained and massive for the most part, but in the Gros Ventre buttes glassy, brecciated and porphyritic facies were noted, and at two exposures south of Wilson the flows are very thin-bedded and have well-developed parting surfaces. At the north end of the Teton Range, Weed and Iddings have described the late basic breccias and rhyolites of the Yellowstone region; both rest on eroded surfaces.[2] It seems probable that the volcanic rocks flanking the range farther south,

[1] Eliot Blackwelder, "The Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, p. 105.

A. R. Schultz, "A Geological Reconnaissance for Phosphate and Coal in Southeastern Idaho and Western Wyoming, *op. cit.*, p. 30.

[2] Arnold Hague, J. P. Iddings, W. H. Weed, *et al.*, "Geology of the Yellowstone National Park," *U. S. Geol. Survey Monograph 32*, Part II (1899), pp. 157; 161–162.

as well as those in Jackson Hole, belong to the late basic-breccia group, which is mainly andesitic, and that the rhyolites, if present, are buried under alluvium. In the Park area the late basic breccias are considered Eocene in age and the rhyolites Miocene.[1]

Later Tertiary Sediments.

In the eastern part of Jackson Hole south of the Gros Ventre River and also northwest of Moran there are extensive areas of Tertiary sediments. The deposits are made up of light-colored clays, tuffaceous sandstones and contain some lava flows. The presence of volcanic material in their composition, together with the fact that similar deposits of known Eocene age are interbedded with andesitic lavas at the west end of the Owl Creek Range,[2] indicate that they are in part contemporaneous with the late basic breccias. Although probably largely Eocene, the presence of younger beds is suggested by the finding of an *Oreodon* skull in the deposits north of Moran.[3]

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[1] Richard M. Field, "Yellowstone–Beartooth–Bighorn Region," *XVI Inter. Geol. Cong., Guidebook 24* (Washington, 1932), p. 9.

[2] David Love, "The Geology of the Western End of the Owl Creek Mountains, Wyoming," *Geol. Survey of Wyo. Bull. 24* (Laramie, 1934), pp. 12–21.

[3] F. M. Fryxell, personal communication.

CHAPTER III

Structural Setting

STRUCTURAL TRENDS IN WESTERN WYOMING AND ADJACENT AREAS

The mountain ranges of the Middle Rockies may conveniently be grouped into eastern and western belts whose distinctive features serve to emphasize important structural differences. Belonging to the eastern division are the outer ranges of Middle Rockies, such as the Beartooth, Owl Creek, Bighorn, and Wind River ranges, and the Black Hills, while the western belt would include the complex mountain units extending southward from Yellowstone Park along the Idaho–Wyoming line as far as the Wasatch Range.

The uplifts of the eastern belt are broad, crustal folds exposing crystalline rocks in their central portions. About their margins the Paleozoic beds form steeply dipping monoclines which pass into horizontal strata bridging the axes of uplift where not stripped away. The marginal structures are often cut by high-angle thrust faults which in some instances grade laterally into steep monoclinal flexures. Certain of the uplifts have broken along thrust faults on either side, fulfilling the requirements of wedge-shaped mountain units. This type is illustrated with varying degrees of perfection by the Beartooth, Bighorn, Owl Creek and Uinta ranges. The Wind River and Gros Ventre ranges, as well as the buried Washaki Range,[1] have been overthrust toward the southwest. The major structural trend is N 30° E, but this uniformity is broken by two groups of related uplifts forming arcuate patterns, the Owl Creek–Bighorn–Pryor arc and the Black Hills–Hartville arc. This feature has been explained by the influence of pre-Cambrian lines of weakness trending slightly south of east upon the normal strike

[1] J. David Love, "Buried Mountain Range in Northwestern Wyoming," *Geol. Soc. Amer. Pro.*, 1936, 1937.

of the Laramide structures.[1] It is also noteworthy that a number of these ranges seem to radiate outward from the center of volcanic activity in the Yellowstone Region. The independent character of the various uplifts is emphasized through separation by broad intermontane basins containing slightly folded and faulted Tertiary sediments.

The ranges of the western belt are typified by a number of intimately related units just to the south of the Teton Pass area, such as: the Snake Range, the Hoback Range, the Wyoming Range and the Salt River Range. Forming a relatively narrow belt, which follows either a northerly or northwesterly direction, the group is made up of a series of parallel structures which persist for long distances. The individual folds are closely compressed and often overturned to the east. Taken together they form a folded system of the Appalachian type. Probably the outstanding feature of the belt is the series of large overthrust faults which to the north are exemplified by the Lewis, Lombard and Heart Mountain faults and farther south by the Darby, Absaroka, Hannock, Willard and Crawford faults (Fig. 7). The horizontal displacement along some of these thrusts is probably more than 30 miles. Westward the structures merge with folding of Jurasside age. It is significant that the western belt is entirely within a geosynclinal area while the ranges to the east are formed of sediments representing foreland facies (Fig. 11).

Although usually separated by considerable distances, the two belts are found to unite at the northwest end of the Beartooth Range, at the north end of the Wind River Range, along the south sides of the Gros Ventre and Teton Ranges, and at the west end of the Uinta Range. Both groups appear to have had their most active movement during the Laramide Revolution, but the buttressing effect suggested in the case of the Uinta, Gros Ventre and Beartooth ranges would indicate that the eastern uplifts are somewhat older than those to the west.[2]

In northern Utah and southeastern Idaho, the Middle Rockies border the Basin-Range Province and within this

[1] R. T. Chamberlin, unpublished manuscript.

[2] See pp. 53–55.

area recent high-angle faults are found in conjunction with the older structures of the western belt of ranges. The best known are the normal faults described by Mansfield in southeastern Idaho[1] and the fault along the west front of the Wasatch Range. Recent block faulting has also been reported north and south of the Snake River plains in Idaho.[2]

REGIONAL STRUCTURES IN THE TETON PASS AREA

Structures of the Eastern Belt.

The structures of the Gros Ventre Range,[3] which enter the area from the southeast, terminate abruptly along the east side of Jackson Hole as the result of cross folding or faulting. To the west these lines of deformation, though transsected by several N-S faults, are preserved in certain of the buttes rising above the floor of the basin and in the Teton Range itself.

The structure of the Gros Ventre Range is similar to that of the Wind River Range and is typical of the eastern ranges of the Middle Rockies. Its general outlines are those of a broad, asymmetrical anticline with steep dips on the southwest and a strike north 40 degrees west. The north slope has been complicated by at least three secondary folds, also with steepened southwest limbs. Their axes follow the courses of Nolan Creek, Flat Creek and the Gros Ventre River and are parallel to the main trend of the range. On the southwest, the flank of the range is broken by a north-dipping thrust fault bringing Madison limestone over Upper Cretaceous beds. Near Jackson this apparently dies in an asymmetrical anticline. In its relation to sedimentary facies, the range is similar to those of the eastern group. Blackwelder reports that the beds are thinner than in adjacent areas to the southwest and that within the range, passing

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[1] G. R. Mansfield, "Geography, Geology and Mineral Resources," *op. cit.*, pp. 162–169.

[2] A. L. Anderson, "A Preliminary Report on Recent Block Faulting in Idaho," *Northwest Science*, Vol. VIII (1934), pp. 17–28.

[3] A detailed study of the structure of the Gros Ventre Range is being made by Vincent Nelson of the University of Chicago.

from west to east, there is a transition from the local formational facies into that of the Wind River Range.[1]

The anticlinal axes following the Gros Ventre River and Flat Creek can not with any accuracy be carried west into the Tetons, but may be represented by the broad pre-Cambrian salients in the northern part of the range. This is suggested by the fact that the Paleozoic strata in Blacktail Butte are in line of strike with those along Flat Creek and that if carried northwest would intersect the Tetons at the required position. Traced westward the "Nolan Creek anticline" appears at the north end of the small butte northeast of Jackson and possibly in the northern slope of the West Gros Ventre Butte where a small exposure of vertical Madison limestone has a strike of north 47 degrees west. In the Teton Range this structure is probably represented by the Moose Creek anticline. The south limb of the main Gros Ventre anticline, which passes into a thrust fault to the east, westward seems to be continued by the sharp flexure at the south end of the East Gros Ventre Butte where the Madison limestone and Wells quartzite strike north 65 degrees west and have a south dip of 40 degrees. North of Teton Pass the same structural trend is represented by the Taylor Mountain anticline.

Structures of the Western Belt.

The folded and faulted structures of the ranges south of Snake River enter the area trending north 20 degrees west and pass into the Snake River Range where, in the northern part, their strike changes to north 60 degrees west. South of Teton Pass this lineament is joined by similar structures extended westward from the north end of the Hoback Range. Both are continued in the Big Hole Range to the northwest.

The Snake River Range is typical of the mountains of the western belt in that it consists of a series of closely folded anticlines and synclines which have been broken along two large west-dipping thrust faults, the Darby and the Absaroka. Crystalline rocks are nowhere exposed in axes of the folds.

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[1] Eliot Blackwelder, "A Reconnaissance of Phosphate Deposits in Western Wyoming," *op. cit.*, p. 467.

The Darby fault was first recognized by Peale[1] and later named by Schultz from Mount Darby in the Wyoming Range.[2] Appearing from beneath the Eocene beds of the Green River Basin, the fault follows the east side of Labarge Ridge, then skirts the north edge of Thompson Plateau and continues west to join the transverse Thompson fault. From that point it forms the regular eastern margin of the Wyoming Range as far north as Snake River where it enters the Teton Pass area and within a distance of four miles terminates in a north-plunging anticline. Its known length is about 100 miles and at several points Mississippian beds are faulted against the Frontier formation, indicating a stratigraphic throw of over 20,000 feet. The horizontal displacement may exceed 15 miles.[3]

The Absaroka fault, which was first reported by Peale,[4] was named by Veatch[5] who mapped its extent in Uinta County, southwestern Wyoming. It has been followed northward by Schultz[6] along the eastern border of the Salt River Range and into the Snake River and Big Hole ranges. The length of the fault is about 200 miles and its stratigraphic throw exceeds 20,000 feet. Mansfield has estimated that its zone of displacement may exceed 25 miles.[7] In the Snake River Range, the Absaroka fault closely follows the main watershed and forms the southwestern boundary of the Teton Pass area. The structures between the two faults are northward continuations of folds in the Wyoming Range and Middle Ridge.

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[1] A. C. Peale, "Report on the Geology of the Green River District," *U. S. Geol. and Geog. Survey of the Terr., Eleventh Ann. Report*, 1879, p. 630.

[2] A. R. Schultz, "Geology and Geography of a Portion of Lincoln County, Wyoming," *U. S. Geol. Survey Bull. 543*, 1914, p. 84.

[3] G. R. Mansfield, "Geography, Geology and Mineral Resources of Southeastern Idaho," *op. cit.*, p. 381.

[4] A. C. Peale, *op. cit.*, p. 546.

[5] A. C. Veatch, "Geography and Geology of a Portion of Southwestern Wyoming," *U. S. Geol. Survey Prof. Paper 56*, 1907, pp. 109–110.

[6] A. R. Schultz, "A Geological Reconnaissance for Phosphate and Coal in Southeastern Idaho and Western Wyoming," *op. cit.*, pp. 66–67, 36–41.

[7] G. R. Mansfield, "Geography, Geology and Mineral Resources of Southeastern Idaho," *op. cit.*, p. 381.

The outermost structural zone of the western belt has its beginning at the north end of Thompson Plateau, from which point a series of narrow folds extends northward along the western edge of the Green River Basin and finally passes into the Hoback Range. North of Hoback Canyon they become closely compressed and terminate with an abrupt change in strike along the southwest flank of the Gros Ventre Range. Throughout most of this distance the folded belt is probably bordered by a thrust fault similar to the Darby and Absaroka to the west. This is suggested by the relations of the folded Mesozoic beds to the Evanston formation (Paleocene) at the east end of Hoback Canyon and on the recent geological map of the U. S. Geological Survey (1933) a fault is shown in dashed lines.[1] The contact between the older deformed beds and the essentially flat-lying Evanston formation along the east margin of the Hoback Range was mapped and interpreted by Schultz as an unconformity of more than 20,000 feet.[2] About five miles northwest of the northern limit of Schultz's mapping of this contact, Cambrian limestones have been thrust northward over Upper Cretaceous beds resting on the floor of the valley of Cache Creek.[3] The Paleozoic strata at this point are essentially in line of strike with those mapped by Schultz to the southeast. This would indicate that the fault turns northwestward and on the south side of the Gros Ventre Range joins with the thrust mapped by Nelson along the south side of Cache Creek. West of Jackson the same structure is preserved in two small buttes located just south of the main Gros Ventre Buttes and continuing across Jackson Hole it is represented by the Teton Pass thrust zone. East of Victor, Idaho, the fault disappears beneath the alluvium of Teton Basin, but reappears again at the northeast end of the Big Hole Range in the Horseshoe and Pine Creek Coal Districts, where carboniferous limestones have been thrust over Upper Cretaceous beds.[4] This structure, which for over

[1] The probable existence of such a fault was first called to the attention of the writer by W. W. Rubey in 1936.

[2] A. R. Schultz, "Geology and Geography of a Portion of Lincoln County, Wyoming," *op. cit.*, Plate I, pp. 68–71.

[3] V. N. Nelson, personal communication.

[4] G. R. Mansfield, "Coal in Eastern Idaho," *op. cit.*, Plate XIV, pp. 138–140.

one hundred miles constitutes a major zone of deformation in the Middle Rockies, is here referred to as the Jackson fault. Typical relations are to be seen in Cache Creek east of Jackson, Wyoming, and along the road from Jackson to Victor across Teton Pass.

Faulting of the Basin-Range Type.

Block faulting of the Basin-Range type is represented by the large fault along the east front of the Teton Range, by the high-angle faults in the southern part of the Tetons, and by fault blocks forming the buttes rising from the floor of Jackson Hole. These structures can not be directly related to lines of deformation in areas immediately adjoining, but high-angle faulting is not uncommon in the region of the south and west. Less than 100 miles to the west is the Lemhi Range fault block, which forms the easternmost range of this type north of the Snake River in central Idaho.[1] In Yellowstone Park it has been suggested that the geyser basins, together with certain lake margins and drainage courses, are aligned along faults.[2] If the dislocation along the front of the Teton Range is projected northward, it is found to coincide with a fault following the Lewis River and marking out the western border of Lewis Lake. Although the Teton fault probably dies before reaching the park, it seems likely that both may be related to a similar structural trend.

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[1] A. L. Anderson, *op. cit.*, pp. 17–28

[2] Emmanuel de Martonne, "Le parc national du Yellowstone equisse morphologie," *Amer. Geog. Soc. Memorial Volume, 1912* (1915), pp. 242–43.

A. K. Lobeck, *Atlas of American Geology* (New York: The Columbia Press, 1932), Sheet No. 65.

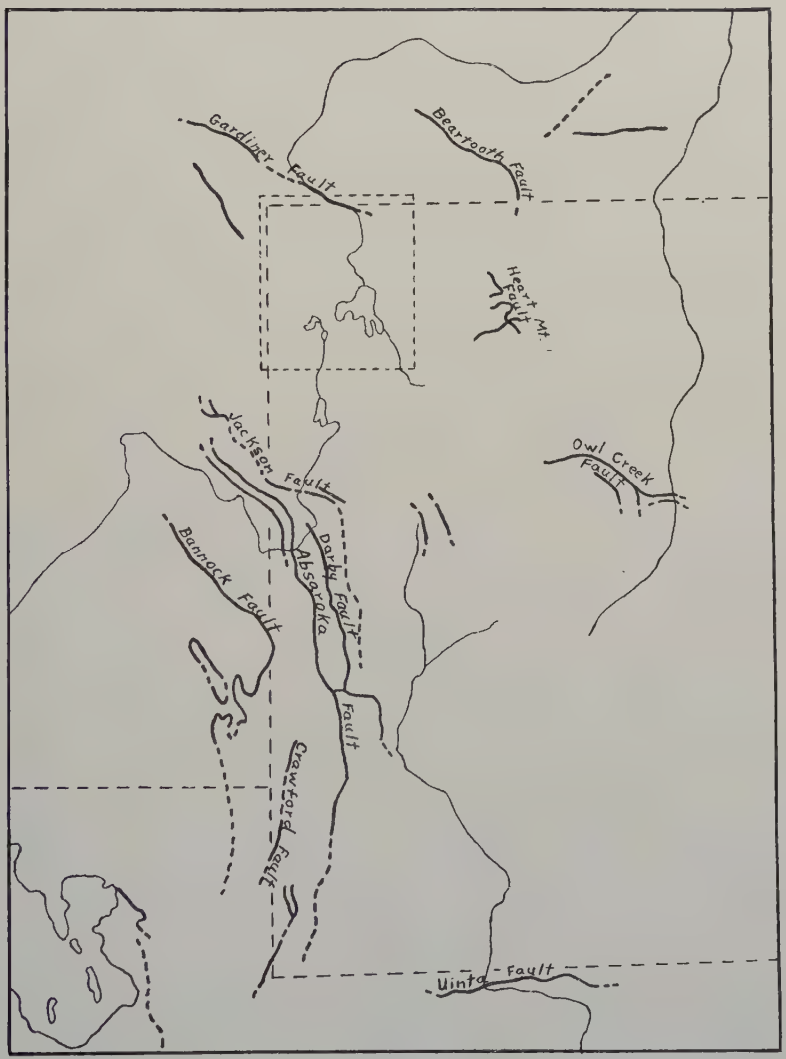

FIGURE 7.
Thrust faults in western Wyoming and adjacent areas.

CHAPTER IV

Description of Structures

GROS VENTRE—TETON ANTICLINES

Folding in the North Part of the Teton Range.

Although eroded and tilted as the result of Tertiary block faulting, Laramide folds of the eastern belt type are preserved in the north part of the Teton Range. These form two broad anticlines and an intervening syncline, which give rise to two salients of crystalline rock separated by an area of Paleozoic sediments. The western salient diverges from the crest of the range near the head of Moran Canyon and extends north 50 degrees west for a distance of five miles before disappearing beneath the lavas of the backslope. The axis of the fold follows the divide between Badger Creek and the North Fork of Teton River and at the contact with the lavas it is about four miles wide. Dips on the flanks of the fold are gentle and the structure as a whole, having been beveled by erosion in pre-volcanic time, exerts but little control on topography. The eastern salient, which trends north 55 degrees east from the same point, follows the divide between Moose Basin and Snowshoe Canyon for a distance of seven miles before being transected by the Forellen Peak fault. Although the pre-Cambrian continues to outcrop to the north, this is in part the result of later faulting. The intervening synclinal axis coincides with the divide between Owl Creek and Birch Creek and has a strike of north 25 degrees west. Beds belonging to the Wells formation are preserved near the center of the fold at Red Mountain.[1] To the west the structure disappears beneath volcanic flows and farther north becomes involved in faulting near the head of Conant Creek. The east limb of the fold ends against the Forellen Peak fault.[2]

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[1] Rudolph Edmund, personal communication.

[2] Structures are shown in Figs. 9, 10, and 17.

The Moose Creek Anticline.

This structure, which may be the westward continuation of the Nolan Creek anticline of the Gros Ventre Range, appears in the Teton Range just south of Rendezvous Peak and continues west along the north slope of the valley of Moose Creek to disappear beneath the lavas near the mouth of Game Creek (Fig. 8, C-C). The average strike is north 85 degrees west. The fold is essentially monoclinal in character with dips as high as 67 degrees on the south limb. North of the flexure the beds immediately resume their gentle northwest dip, and to the south become involved in other structures. The youngest beds involved in the folding are those of the Wells and Madison formations; the Cambrian Flathead is exposed in the core of the fold at the forks of Moose Creek. At about its midpoint the structure has been broken by the north-south trending Open Canyon fault and to the east it passes into the Rendezvous Peak fault.

The Taylor Mountain Anticline.

Representing the probable continuation of the main Gros Ventre anticline, this fold becomes apparent in the Teton Range at the pass and from this point trends north and west until it passes below the lavas near the mouth of Moose Creek (Fig. 8, A-A, C-C). On the south flank of Taylor Mountain the beds forming the south limb strike north 50 degrees west and dip 60 degrees to the south. The structure is similar to the Moose Creek anticline in its asymmetry, its general trend, and in the beds involved. On the south the fold has been partially covered by the over-riding block of the Jackson thrust fault (Figs. 8 C-C; 9), from beneath which progressively younger beds emerge on the west. Along Teton River the Cambrian limestone of the thrust sheet has a strike of north 55 west, while the Mesozoic beds to the north, forming the south limb of the fold, trend north 30 degrees west. These relations are significant, since they evidence the older age of the Taylor Mountain anticline and similar structures of the eastern type. The fold has been modified further by high-angle faults in Coal Creek and Phillips Canyon.

The Phillips Pass Syncline.

The irregular downfold between the anticlines just discussed is best exposed at Phillips Pass where the red beds of the Ankareh formation are preserved in its center. At this point the synclinal axis has a strike of about north 75 degrees east. The structure has been modified on all sides by later faulting and to the west is partly concealed beneath lava flows.

SNAKE RIVER RANGE STRUCTURES

The Absaroka Fault.

The Absaroka fault, which forms the southwest boundary of the area, was located by the writer near Smoky Hol Peak and on South Fall Creek, and Schultz has described it from near the head of Elk Creek and in the canyon of Snake River.[1] Within the area mapped the Wells formation is thrust eastward over upper Cretaceous beds, although just to the west the Beckwith formation forms the underlying block. The fault trace is sinuous in character and has an average strike of north 20 degrees west. Throughout its length the fault scarp is a prominent topographic feature; the main peaks of the Snake River Range are found just west of the fault and are bordered on the east by a lowland belt in the weaker Cretaceous beds.

The Darby Fault.

The Darby fault crosses Snake River and enters the area in the vicinity of Counts Hot Spring. At this point the strike changes from north 25 degrees west to north 5 degrees west and the structure becomes complicated by minor faulting and folding. Just north of the river, where the beds are well-exposed, the Wells formation has been thrust eastward over the west limb of a steeply-dipping syncline in which the oldest formation revealed is the Twin Creek limestone. The Wells formation is dipping 33 degrees to the west and beds east of the fault dip 70 degrees east. Traced northward the displacement becomes less and less

[1] A. R. Schultz, "A Geologic Reconnaissance for Phosphate and Coal in Southeastern Idaho and Western Wyoming," *op. cit.*, Plate I, p. 12.

until on Fall Creek the Dinwoody is faulted against the Gannett group and, about half a mile beyond, the fault ends in a north-plunging anticline. Numerous traverses made along the east slope of the Snake River Range north of this point failed to uncover any evidence of faulting east of the Absaroka fault. The thrust fault in the Big Hole Range, formerly regarded as the Darby fault, is an independent structure, here referred to as the Jackson fault.

The Jackson Fault.

One of the most striking geological features of the region is the abrupt termination of the structures of the Snake River Range where they meet the south end of the Tetons at Teton Pass. The change in structure is reflected by changes in the prevailing strike of the formations, the degree of deformation, and in topography. South of the pass there are closely folded Mesozoic beds; north of the pass there are gently dipping Paleozoics. The points of contrast are essentially those which distinguish Laramide folding of the western type from an area in which Laramide structures of the eastern belt have been later uplifted by faulting. The northern margin of the western zone of deformation is marked by the south-dipping Jackson fault.

Though sinuate in character, this thrust has an average strike of north 20 degrees west. Appearing from beneath the lavas east of Victor, Idaho, it continues east along the south side of the valley of Teton River, across the pass into Jackson Hole, and into the Gros Ventre Range. Throughout this distance it quite closely follows the highway between Victor, Idaho, and Jackson, Wyoming. The best exposures of beds along the fault are at the pass itself and along the valley to the west. The fault plane is nowhere exposed, but its angle of dip must be less than 30 degrees for at several points Mesozoic strata occur immediately below and behind the outer margin of Paleozoic outcrops. At Teton Pass, just south of the road, the Gallatin limestone has been thrust over the Twin Creek formation; about a quarter of a mile to the west the same formation is resting on the Nugget sandstone; and, near the mouth of Mail Cabin Canyon a prominent hill composed of beds ranging in age from Cam-

brian to Mississippian rises above a Mesozoic area to the west in which the youngest formation recognized was the Aspen (Fig. 8, A-A). These relations indicate that there was some erosion of the southwest limb of the Taylor Mountain anticline before thrusting. East of the pass the relations along the fault are obscured, and, although the strike on either side remains essentially the same, it seems likely that the structure has been modified by a later east-west trending high-angle fault. The stratigraphic throw of the Jackson fault is here about 3000 feet. Associated with the major thrust are a number of minor folds and slice faults, some of them too small to be shown on the map. This zone of erratic structure extends south as far as the north slope of the valley of Mosquito Creek. Along the ridge trending south from Teton Pass, the Gallatin limestone and Bighorn dolomite occur at three different points as the result of imbricate faulting. West of the pass the thrust sheet has buckled into a narrow anticline involving the Cambrian and Ordovician. Along a line coinciding more or less with Black Canyon, the uniform strike of the beds south of the fault is broken along a shift zone in which the east side moved north relative to the west. In the two small buttes southwest of Jackson, which preserve the eastward continuation of the structure, the beds forming the footwall of the fault are concealed, but the imbricate faulting and close folding of the thrust sheet are well shown. The beds here are in line of strike with those south of the pass, while in the larger buttes adjacent to the north, the dip and strike is similar to that north of the pass. To the east the fault continues along the south side of Cache Creek in the area mapped by Nelson.

Minor Structures in the Snake River Range.

East of the Absaroka fault the Upper Cretaceous beds have been folded into a series of anticlines and synclines paralleling the trend of the range. These are not shown on the areal map but were observed at numerous points on the east flank of the range. On the south side of Mosquito Creek, the Gannett group and Stump-Preuss formations are revealed in the core of an anticline bordering the Absaroka fault.

The Teton Fault.

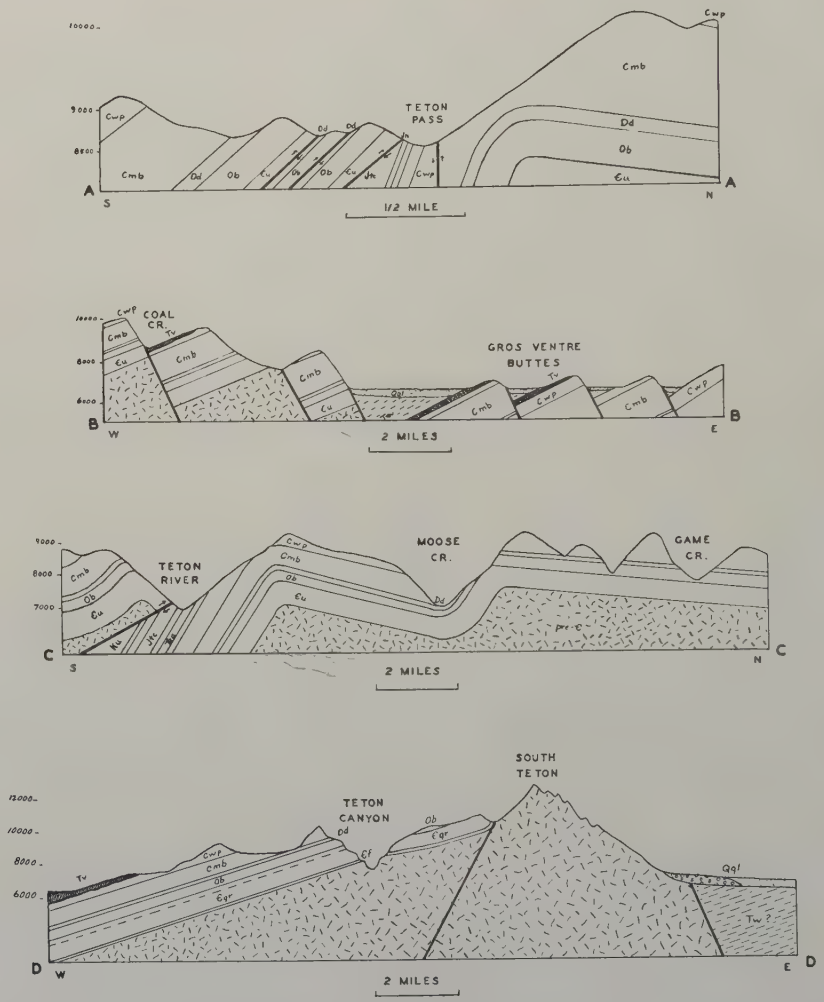
The imposing east front of the Teton Range has long been regarded as a scarp due to faulting.[1] Constituting one of the outstanding examples of its type on the continent, it is equalled only by the east face of the Sierras and possibly by the Wasatch Range scarp.[2] On the basis of physiographic data there is convincing evidence of the existence of a high-angle fault along the east face of the range. The major features indicative of faulting are: the linear base with complete absence of foothills, the abruptness and continuity of the front, the hanging valleys, and the triangular facets at the distal ends of the short, steep spurs (Fig. 5).

For a distance of forty miles north from Wilson, the Teton fault is a preëminent topographic feature, giving rise to an imposing wall of Paleozoic and pre-Cambrian rock rising precipitously from the flats of Jackson Hole (Fig. 8 D-D). The average trend of the fault is north 10 degrees west, and, except for the reëntrant and slight change of bearing at the mouth of Death Canyon, the strike is uniform. The dip of the fault is not known, but must be something over 40 degrees as the best preserved facets along the scarp have this average slope. Near Jenny Lake the exposed scarp of the fault is over 7000 feet high and the true displacement is doubtless considerably more, as the figure given does not allow for stratigraphic throw nor for the amount of pre-Cambrian rock removed by erosion.[3] South of the main peaks the throw gradually diminishes until the sedimentary rocks appear in the fore peaks and the main fault branches in the vicinity of Phillips Canyon to form the Wilson ridge block. The faults on either side of this ridge appear to terminate abruptly at its southern end, probably being cut off by a cross fault following the course of Trail Creek. At the north end of the range the main

[1] Eliot Blackwelder, "The Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, pp.114–115, 214–215.

[2] The question of whether the scarp represents a recent fault scarp, a composite fault scarp, or a fault-line scarp will be discussed in another connection.

[3] Blackwelder estimated the stratigraphic throw as not less than twice this amount. *Ibid.*, p. 114.



TETON PASS AREA

STRUCTURE SECTIONS

FIGURE 8.

Structure sections. Pre-C, pre-Cambrian; Cu, Cambrian undifferentiated; Cf, Flathead quartzite; Cgr, Gros Ventre formation; Ob, Bighorn dolomite; Dd, Darby formation; Cmb, Madison-Brazer limestone; Cwp, Wells and Phosphoria formations; Trd, Dinwoody formation; Tra, Ankareh shale; Jn, Nugget sandstone; Jtc, Twin Creek limestone; Ku, Cretaceous undifferentiated; Tv, Tertiary volcanics; Tw, Tertiary sediments; Qgl, glacial deposits.

fault rapidly diminishes in displacement so that Cambrian and Ordovician strata appear at the front of the range near the north end of Jackson Lake.[1] From Waterfall Canyon northward, the main line of displacement seems to be continued by the Forellen Peak fault which probably comes to the front of the range near the mouth of that canyon.

The Buck Mountain Fault.

When the main Teton peaks are viewed from the north or the south, it becomes evident that the eastward projection of the sedimentary beds of the backslope would fall short of clearing their summits without assuming an abrupt flexure or fault behind the main crestline (Fig. 8 D-D). This portion of the range, including all the major peaks between Death Canyon and Cascade Canyon, thus represents an upthrust wedge rising above the outlines of the Teton block and directly responsible for the superior elevation of the high peaks.[2] This zone of deformation may be observed in the Cambrian beds at the head of Avalanche Canyon where dips ranging from 60 degrees west to vertical were measured near the contact with the crystalline rocks. Although it is difficult to imagine such an abrupt stratigraphic break as due to folding alone, direct evidence of faulting is not apparent at this point. However, in the saddle just west of Buck Mountain the Death Canyon member of the Gros Ventre formation dipping 30 degrees west occurs about 150 yards west of the pre-Cambrian wall forming the west side of Buck Mountain. The evidence of faulting appears to be supported by displacement of the east-west trending basic dikes in South Cascade Canyon. Behind Buck Mountain and the South Teton the throw of the fault could not have been less than 1000 feet. To the south the fault probably joins the Teton fault and is responsible for the reëntrant in the front of the range at the mouth of Death Canyon. Northward the fault passes into the pre-Cambrian and gradually dies out, as north of Cascade Canyon the Cambrian could be carried without break to the front of the range.

[1] F. M. Fryxell and Howard Stagner, personal communication.

[2] This fault was discovered by F. M. Fryxell in August, 1929.

The Table Mountain Fault.

In the saddle immediately south of Table Mountain the Cambrian beds have been displaced along a high-angle fault trending slightly north of west. The Flathead quartzite at this point rests against the Gros Ventre evidencing a displacement of about 400 feet with upthrow on the north. To the west the fault rapidly dies out, as there is no noticeable displacement along Teton Canyon which is in its line of strike. This indicates that the fault is of the hinge type and if continuous to the front of the range would there have its maximum throw. The alignment of Teton Canyon, the saddle south of Table Mountain, and col between Grand Teton and Middle Teton, and the steep south face of the Grand Teton suggests fault control, though direct evidence of faulting in the pre-Cambrian has not been noted. If the fault is assumed to continue to the east, it may well explain the superior elevation of Grand Teton which rises about a thousand feet higher than the summits to the south.

The Open Canyon Fault.

Along Open Canyon and continuing southwest across the trend of the range there is another high-angle fault of the hinge type. In the saddle between Mount Hunt and Prospector's Mountain the lower quartzite of the Wells formation has been faulted against the pre-Cambrian which forms the steep slope to the north. The throw here is estimated as about 2800 feet and the strike of the fault is north 50 degrees east. From this point the fault swings to the south and diminishes in displacement until at the head of south Granite Canyon the Bighorn is faulted against the Madison-Brazer. Here the fault plane, which is well-exposed, dips 63 degrees to the east and has a strike of north 35 degrees east. The throw is about 500 feet. Near the forks of Moose Creek the fault is lost in the steeply dipping Cambrian beds forming the south limb of the Moose Creek anticline, but the same line of fracture is continued to the south by a fault along Coal Creek. Due to uplift of the block to the west, the throw of the fault increases to well over a thousand feet where the Wells quartzite is faulted against Cambrian and Ordovician strata (Fig. 8, B-B). The fault ends in the

steep south limb of the Taylor Mountain anticline near the mouth of Coal Creek, there being no evidence of this displacement in the beds along Teton River.

The Rendezvous Peak Fault.

At the head of the north fork of Phillips Canyon, just south of Rendezvous Peak, the beds forming the south limb of the Moose Creek anticline have broken along a high-angle fault trending east-west. To the south the beds of the downthrow block are dipping about 45 degrees south, while those on the upthrow side dip northwest at a slight angle. Near the fault line the beds on either side are dipping away from the fault plane giving rise to the anomalous feature of down drag on both blocks. This is best explained by assuming that following the main displacement with downthrow on the south there was a slight relaxational movement with downthrow on the north. The Darby formation is resting against the Bighorn dolomite indicating a stratigraphic throw of about 300 feet and the fault plane appears to be essentially vertical. To the east a rapid increase in the amount of displacement is evidenced by the difference in elevation (about 1500 feet) between the top of the pre-Cambrian on either side of the fault as it comes to the front of the range and indicates another fault of the hinge type.

Faulting in Phillips Canyon.

The faulting in Phillips Canyon is to be related to branching of the Teton fault, one branch following along the mountain front and the other, with subsidiary faults, continuing southwest as far as Trail Creek. On the north the main Phillips Canyon fault[1] has brought the Madison-Brazer against the Wells on the east and, near Trail Creek, Tertiary volcanics are faulted against the pre-Cambrian (Fig. 8, B-B). On either side of the fault the beds are dipping northwest at gentle angles. Just west of the main branch of the canyon a downdropped block of Madison-Brazer and Wells intervenes between the normal sequence of Paleozoics on the west and the tilted block to the east giving rise to Wilson Ridge.

[1] This fault was first reported and named by Blackwelder in 1915.

Faulting along Trail Creek.

Although direct proof is wanting, there is circumstantial evidence of an east-west hinge fault following the course of Trail Creek from Teton Pass to the foot of the range. Exposures within the valley itself are covered, so interpretation is based upon outcrops along the slopes on either side. The steep south limb of the Taylor Mountain anticline can be traced to a point just west of the pass, but east of the pass there is no evidence of this flexure, and the Paleozoic beds continue south into the valley with normal, gentle dips to the northwest. It is possible that a change in strike of this fold would bring the south limb completely below the Jackson thrust, but it seems more probable that it would continue along its normal strike which would necessitate faulting. A fault of this type would also explain the abrupt termination of the main fault in Phillips Canyon and the absence of features due to high-angle faulting along the west edge of Jackson Hole south of Wilson.

Fault Blocks in Jackson Hole.

The Gros Ventre Buttes north of Jackson are similar to each other in their strike, structure and composition. They are made up of gently dipping Paleozoic strata associated with lava flows, which have been tilted westward along faults forming their eastern scarp slopes, similar beds appearing in successive buttes (Fig. 8, B-B). The uniformity of dip and repetition of similar beds led Blackwelder to interpret the structures as due to normal faulting.[1] Due to a fortunate circumstance this conclusion has been verified by the uncovering of the actual fault plane along the scarp of East Gros Ventre Butte near the west edge of the town of Jackson. At this point a tunnel dug by Karl Kent has penetrated the cover of talus and revealed the fault plane for a distance of about 20 feet. The strike is north 30 degrees east and the dip 48 degrees southeast. The slickensided and polished surface of Madison limestone forming the footwall is in contact with breccia and talus on the east. This discovery strongly supports the view that all the buttes

[1] Eliot Blackwelder, "A Reconnaisance of the Phosphate Deposits in Western Wyoming," *op. cit.*, p. 466.

rising from the alluvium-covered floor of the basin are of similar origin.

South of the main Gros Ventre Buttes are two smaller masses of Paleozoic limestone in which the folded and faulted structures have the same trend as the Jackson fault. As a result of normal faulting, beds probably representing a portion of the thrust sheet have been brought to the surface and serve to connect the structures across the basin.

Near the center of the Hole, Blacktail Butte stands as an island surrounded on all sides by an expanse of sage-covered outwash plain. The essential geological features are set forth by Blackwelder:

> In Blacktail Butte, near Gros Ventre post office, the main ridge is reported by Mr. Breger to consist of the Madison limestone flanked on the southwest by soft Tertiary (Eocene?) sedimentary beds. The Madison of the ridge forms an upright compressed anticline, and along the edge of the butte a syncline is traceable southwest of it. In this syncline the quartzite is exposed, but there is no evidence of the existence of the phosphatic series.[1]

Signal Mountain, near Moran, is the largest of the buttes in the northern part of Jackson Hole, and is similar to those near Jackson in being composed of Paleozoic limestone capped by volcanic flows. Nothing is known regarding the geology of the smaller buttes to the east and north.

Faulting in the North Part of the Teton Range.

In the north part of the Teton Range an extensive area of sedimentary beds appears from beneath the volcanic flows and reveals the east pre-Cambrian salient and the syncline to the west, modified by faults parallel to the axis of the folds. This area includes the northern part of the Grand Teton sheet and the southern part of the Shoshone sheet to a point within two or three miles of the Yellowstone Park boundary. There are two important faults shown within the area mapped by Iddings and Weed, one extending south from the head of Conant Creek and the other, which passes through the summit of Forellen Peak, marks the

[1] *Ibid.*, p. 466.

western border of the crystalline axis.[1] The Forellen Peak fault appears as a small displacement along the west flank of the plunging anticline east of Survey Peak where the Devonian is faulted against the Madison limestone. To the south the stratigraphic displacement increases, with the Madison faulted against the pre-Cambrian in Forellen Peak. From this point south the fault swings to the east, passing through the saddle east of Ranger Peak, where the Flathead quartzite is in contact with the pre-Cambrian, and probably joining the Teton fault near the mouth of Waterfall Canyon on the west side of Jackson Lake. At the head of Conant Creek Upper Cretaceous shales have been faulted against the Madison to the east along a normal fault which traced southward comes to involve the volcanic breccias and flows covering the older sedimentaries on the downthrow block.[2] Blackwelder has estimated the displacement along this fault as not less than 1500 feet.[3] Since both of these faults cut the older folded structures and one of them involves the volcanics, they are regarded as Tertiary in age and contemporaneous with the uplift of the Teton block.

STRUCTURES IN THE PRE-CAMBRIAN OF THE TETON RANGE

The structures of the crystalline rock of the Teton Range await detailed investigation and the remarks which follow are intended only to point out certain broad features which may be of general interest and also have a bearing upon younger structures. Throughout the length of the range the foliation in the prevailing gneiss and schist has moderate to steep dips and the strike closely follows the trend of the mountain front. From Death Canyon north as far as Mt. Moran the dip is uniformly to the east with angles ranging up to 70 or 80 degrees. The bristling appearance of the main peaks with their numerous spire-like summits is

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[1] J. P. Iddings and W. H. Weed, "Descriptive Geology of the Northern End of the Teton Range," *U. S. Geol. Survey Mon. 32, Part II, Geology of the Yellowstone National Park (1899)*, pp. 150, 158, 159, 161, Plate XXIII.

[2] *Ibid.*, Plate XXIII.

[3] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, p. 113.

directly related to this structure as well as to jointing.[1] North and south of this area representing the axis of maximum uplift, changes to prevailing west dips[2] have been noted which suggests pre-Cambrian faulting along east-west lines. In appearance the crystalline rocks seem to be shattered by innumerable fractures representing a joint system with east-west master joints and faults of pre-Cambrian and later age. A later fault is thought to exist between the two summits of Mt. Moran where the exhumed pre-Cambrian surface has probably been downdropped on the east along a north-south fault. Along the east wall of of the south branch of Moran Canyon and also along the west base of Mt. Owen and the three Tetons there is strong physiographic evidence of other north-south faults, and there is some reason to think that an east-west fault runs between Mt. Moran and Bivouac Peak.[3]

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[1] F. M. Fryxell, "The Tetons," *Mountaineering Journal*, Vol. II (London, 1934), pp. 150–56.

[2] F. M. Fryxell, personal communication.

[3] *Ibid.*

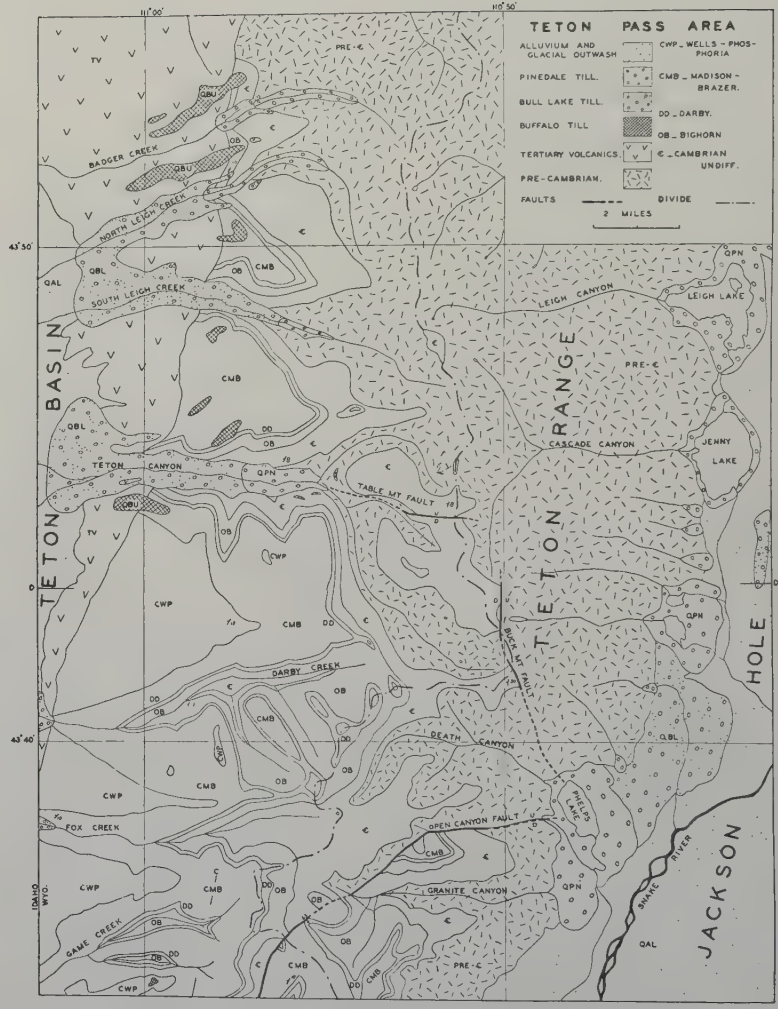

FIGURE 9.
Areal geology of the northern part of the Teton Pass Area.

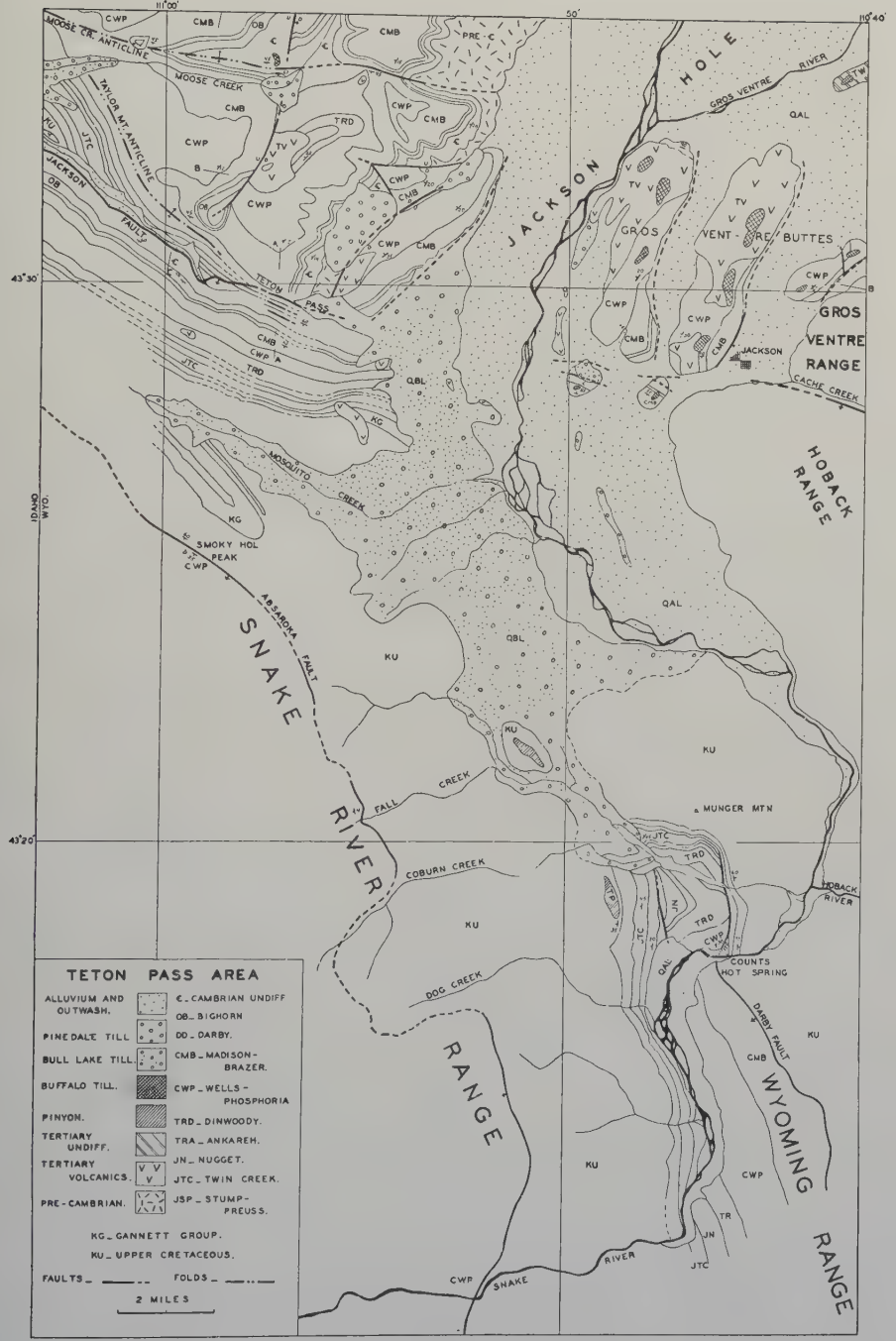

FIGURE 10.

Areal geology of the southern part of the Teton Pass Area.

CHAPTER V

Interpretation of Structures

chronologic development

Two distinct structural types represented within the area, the Laramide folds and thrust faults and the high-angle faults of the Basin-Range type, have been noted; and distinctions have been made between the Laramide structures of the eastern and western belts of the Middle Rockies. Morphologically these types are clear-cut, but whether they represent chronologic differences remains to be considered.

Laramide Structures.

In the Teton Pass area the period of diastrophic movement responsible for the formation of the Gros Ventre-Teton anticlines and the folds and thrust faults of the Snake River Range occurred after the deposition of the Frontier formation and prior to the laying down of the Pinyon (Almy) conglomerate. Beds resembling the Evanston formation occur conformably below the Pinyon (Almy) on the east side of Snake River south of Jackson.[1] This suggests that deformation took place in pre-Evanston time, which is in conformity with conclusions reached by Schultz and Veatch in areas to the south where the major unconformity is between the Adaville and Evanston formations.[2] Since the Evanston is generally regarded as Laramie in age, and may contain Fort Union equivalents, the period of mountain making here conforms in general to the age of Laramide deformation elsewhere in the Rocky Mountains.

Although belonging to the same general period of mountain making, the relations of the two types of Laramide

[1] A. R. Schultz, "A Geologic Reconnaissance for Phosphate and Coal in Southeastern Idaho and Western Wyoming," *op. cit.*, p. 30.

[2] A. R. Schultz, "Geology and Geography of a Portion of Lincoln County, Wyoming," *op. cit.*, pp. 68–71.

A. C. Veath, "Geography and Geology of a Portion of Southwestern Wyoming," *op. cit.*, p. 75.

structure represented in the area suggest that here, as elsewhere within the Rocky Mountains, the time of deformation covered a considerable interval and that the various structures are not exact time equivalents. It is thought that the Gros Ventre-Teton anticlines, representing folds of the eastern type, were developed somewhat before the structures of the Snake River Range, which typify the western group, and that the earlier structures acted as buttresses for the later ones. This relationship is best shown along the Jackson fault where the south limb of the Taylor Mountain anticline and the main Gros Ventre anticline have been partially covered by the thrust sheet, giving rise to an abrupt termination of the structures of the Hoback and Snake River ranges in the vicinity of Teton Pass and along the south side of the Gros Ventre Range. West of Teton Pass the earlier trends diverge from the strike of the beds forming the thrust block with an angular difference of about 30 degrees and progressively younger strata appear from beneath the thrust sheet. The abrupt change in strike of the outermost structures of the western type where they meet the south end of the Gros Ventre Range and also where the northwest trend is resumed at the southwest end of the Teton Range, suggests a control exerted by earlier uplifts. The fact that the footwall block of the Jackson fault west of the pass is made up of beds ranging in age from Nugget to upper Cretaceous and that along Cache Creek the thrust sheet rests on upper Cretaceous to Ankareh strata,[1] points to considerable erosion of the older folds prior to thrusting. A similar buttressing effect has been suggested at two other points of junction of structures belonging to the eastern and western groups: at the west end of the Uinta axis[2] and at the northwest corner of the Beartooth Range.[3]

Tertiary Faulting.

The period of Laramide deformation was followed by a long interval of erosion during which the older structures

[1] Vincent Nelson, personal communication.

[2] B. S. Butler, G. F. Loughlin, and V. C. Heikes, "The Ore Deposits of Utah," *U. S. Geol. Survey Prof. Paper 111*, 1920, pp. 251–254.

[3] Edward C. H. Lammers, "The Structural Geology of the Livingston Peak Area, Montana," *Jour. Geol.* Vol. XLV (1937), p. 293.

were worn down to a surface of low relief. This was followed by extensive outpourings of lava which came to rest on rocks ranging in age from pre-Cambrian to upper Cretaceous and gave rise to one of the most conspicuous unconformities in the region. It is highly probable that the present Teton Range was entirely covered by flows extending unbroken from Teton Basin into Jackson Hole. Later the volcanic cover and underlying bedrock was involved in faulting which gave rise to the Teton block and associated high-angle faults. Stripping back of the flows on the backslope of the range in late Tertiary and Pleistocene time has revealed the older structures.

Along the backslope of the Teton Range the pre-volcanic surface truncates the west pre-Cambrian salient so that between Badger Creek and the north fork of Teton River the flows are resting on crystalline rocks. To the south and north successively younger rocks appear from beneath the flows until east of Victor along Teton Creek and near the head of Conant Creek in the north part of the range the volcanics rest on upper Cretaceous beds. The striking uniformity of the west slope of the range is largely due to the uncovering of this base-leveled surface. In detail this unconformity is well shown at the head of Phillips Canyon where the south limb of the Philips Canyon syncline involving the Wells-Phosphoria, Dinwoody and Ankareh, has been beveled by erosion, covered by flows and later tilted to the west. In the north part of the Snake River Range volcanic remnants were found resting on beds ranging in age from Wells to upper Cretaceous and at the north end of the Tetons the volcanics cover rocks ranging in age from the pre-Cambrian to the upper Cretaceous.

The post-volcanic age of the high-angle faulting is evidenced at a number of points within the area. Eruptives are involved in faulting in the Gros Ventre Buttes, along the main fault in Phillips Canyon, at the head of Coal Creek and along the Conant Creek fault in the northern part of the Teton Range. Tilting of the volcanics on the backslope of the Teton block is shown by the dip of flow layers in places, and by the fact that the lavas are found at elevations ranging from 7000 feet to over 9000 feet without perceptible

thickening in the direction of Teton Basin. In the north part of the Teton Range, Laramide folds have been cut by the Forellen Peak and Conant Creek faults, and in the southern part, the Moose Creek and Taylor Mountain anticlines have also been modified by faulting. Near Jackson, the structures of the Gros Ventre and north Hoback ranges have been transected on the west by the Teton fault and by either faulting or cross folding along the east side of the basin.

From the evidence available within the area only an approximate age can be given for the period of faulting. It is known to have occurred following early Tertiary sedimentation and rhyolite extrusion and prior to the earliest Pleistocene glaciation. The sediments are largely Eocene, but may contain some Oligocene beds, and the rhyolites have been generally considered Miocene. Because of the importance of middle Miocene deformations elsewhere in the Cordilleran region, Blackwelder suggested a similar age for the faulting and warping evidenced in western Wyoming.[1] To the writer an even later age seems probable in the light of recent seismic activity and certain lines of physiographic evidence. Earthquake shocks have been felt in Jackson Hole at various times since the settlement of the region in the eighties, the latest occurring in 1932,[2] and at two points along the front of the Teton Range small scarplets in Paleozoic rocks suggest recent faulting or slides occasioned by faulting.[3] In the northern part of the Teton Range there are two flat summit areas which Blackwelder considered possible remnants of the Pliocene peneplain developed during the Fremont cycle ("Summit peneplain") in adjacent areas.[4] These surfaces are now believed to represent the exhumed pre-Cambrian peneplain,[5] which obviates the necessity of al-

[1] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, pp. 112–117.

[2] Eliot Blackwelder, "Earthquakes in Jackson Hole, Wyoming," *Bull. Seismological Soc. Amer.*, Vol XVI (1926), p. 196.

F. M. Fryxell, "Earthquake Shocks in Jackson Hole, Wyoming, *Bull. Seismological Soc. Amer.*, Vol. XXIII (1933), pp. 167–8.

[3] Phillips Canyon and east of the summit of Mt. Hunt.

[4] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, pp. 200–201.

[5] F. M. Fryxell, personal communication.

lowing for the post-faulting peneplanation favored by Blackwelder.

Resumé of Diastrophic History.

Four periods of important diastrophic movement are recorded within the area and others affecting adjacent regions are represented by breaks in sedimentation or marked changes in lithology. Those directly responsible for local structural and physiographic features occurred during the pre-Cambrian, at the time of the Laramide revolution, during the late Tertiary (post-Miocene), and in the Pleistocene. In adjoining regions less marked disturbances are post-Devonian, post-Pennsylvanian and early Triassic and to the west a large area was affected by the post-Jurassic Sierra Nevada revolution.

The crystalline rocks of the Teton Range show that after a long period of sedimentation and igneous activity, covering an unknown span of pre-Cambrian time, there was metamorphism and folding along north-south lines. This was probably followed by high-angle faulting in an east-west direction and by the intrusion of basic dikes. During the ensuing period of peneplanation the older structures were worn down to a remarkably uniform surface, which nowhere seems to have a relief greater than 50 feet, and on which the Flathead sands were deposited.

In post-Devonian time the early Paleozoic formations were gently folded along an axis trending northeastward across Wyoming from northern Utah, so that when the Mississippian seas advanced after an erosional interval, limestone was deposited on beds ranging in age from pre-Cambrian to Devonian.[1] Post-Pennsylvanian movement is locally indicated by an unconformity at the base of the Wells and by changes in sedimentation responsible for phosphate accumulation. Mountain building of considerable significance occurred in Colorado at this time. The Triassic disturbance was most pronounced farther north in Montana where the marine Jurassic formations rest upon the Phosphoria and to the west truncate successively the

[1] C. W. Tomlinson, *op. cit.*, pp. 392–394.

various Triassic beds.[1] Following the deposition of the marine Stump formation, the area to the west was subjected to widespread deformation which caused a pronounced change in conditions of deposition in western Wyoming and eastern Idaho, where the Gannett group consists largely of coarse clastics of continental origin.

In the Teton Pass area the earliest wave of the Laramide disturbance probably resulted in the folding of the Gros Ventre-Teton anticlines along a southeast-northeast direction. Somewhat later, similar stresses from the southwest became active in the geosynclinal area to the south, giving rise to a system of close folds which broke along several low-angle faults. Moving eastward the outermost zone of deformation involving the Jackson fault probably impinged upon the earlier axis and caused the marked change of strike noted along the south side of the Gros Ventre and Teton ranges. During early Tertiary time the Laramide structures were eroded to a surface of low relief which was locally covered by volcanic eruptives. High-angle faulting followed in post-Miocene time and with contemporaneous uplift of the Teton block, the lavas were stripped back to their present position on the west flank of the range. Widespread epeirogenic movements during the Pleistocene are responsible for rejuvenating drainage and giving to the area its present mountainous aspect.

RELATION OF STRUCTURE TYPES TO THE ROCKY MOUNTAIN GEOSYNCLINE

It has been generally recognized that mountain building is in most cases localized along geosynclines and that variations in thickness and lithology within the trough of deposition are reflected in later structures. Located near the northern portion of the Rocky Mountain geosyncline, the Teton Pass area holds a critical position, where changes in structure types might be expected as the sediments grade from geosynclinal facies to foreland facies. That such changes occur, is shown by the differences existing between the two types of Laramide structures previously described; those of the eastern belt clearly reflect the thinning of sedi-

[1] D. D. Condit, *op. cit.*, pp. 114, 120–121.

ments to the east and those of the western belt are related to geosynclinal facies which characterize the region to the southwest. This coincidence is well shown by Fig. 11, which is based on Forrester's isopach map[1] and data assembled from various publications dealing with the geology of adjoining areas.

The Rocky Mountain geosyncline is a north-south trending downwarp which, without very great interruptions, formed a site of deposition from Cambrian to upper Cretaceous time.[2] The deepest portion of the trough was in southeastern Idaho where more than 46,000 feet of sediments were laid down[3] From this point there is a relatively rapid thinning to the north, so that in the Teton Pass area the total thickness of the Paleozoic and Mesozoic section is less than 12,000 feet. The increase in bulk of deposits in southeastern Idaho, accomplished by thickening of formations and by the appearance of new formations, is shown to be true of practically all Paleozoic and Mesozoic systems. In upper Cretaceous time the site of deposition shifted eastward and conditions of more widespread sedimentation prevailed. On the west the geosyncline is bordered by an area folded and intruded by batholiths following the Jurassic and later subjected to erosion, whereas to the east deformation did not occur until Laramide time.

The structures of the eastern belt of the Middle Rockies, although located outside the area of maximum horizontal compression and involving non-geosynclinal facies, have few of the characters usually associated with foreland folds, which are generally minor structures showing relatively slight vertical uplift. They are instead major orogenic uplifts in which the vertical component is of prime importance, and the stresses responsible for deformation were of deep-seated origin. The western orogenic belt exhibits all of the features normally developed in moderately deformed geosynclinal mountains; the folds are of the Appalachian type,

[1] J. D. Forrester, "Structure of the Uinta Mountains," *Bull. Geol. Soc. Amer.*, Vol. XLVIII (1937), Fig. 1, p. 635.

[2] A part of the area was probably receiving sediments during Proterozoic (Beltian) time.

[3] G. R. Mansfield, "Geography, Geology, and Mineral Resources of Part of Southeastern Idaho," *op. cit.*, p. 48.

there has been extensive low-angle thrust faulting and the stresses involved were shallow in origin and resulted in important horizontal compression. From these considerations it seems probable that the earlier forces were active in the basement complex and resulted in broad domal anticlines in which the crystalline rocks are now revealed. The asymmetrical character of most of these flexures, as well as their irregular trend, suggests control by structures in the pre-Cambrian.[1] In the western belt the forces were active within the sediments themselves and shearing occurred above the basement rocks, which are nowhere exposed within the deformed area. In contrast with the foreland area, where there was marked vertical uplift, within the synclinal wedge there was downward extension of folding with a minor amount of uplift. As in similar couples involving a geosyncline and adjacent land mass, the stresses were probably rotational in character and came from the positive area supplying most of the sediments, i. e., from the west.

THE TETON FAULT BLOCK

Basin-Range Type.

In common with other block mountains, the Teton Range exhibits most of the physiographic features usually associated with high-angle faulting: the linear mountain front, faceted spurs, hanging valleys, and an asymmetrical profile with the watershed well in back of the high peaks. In addition, it portrays surprisingly well the four major elements considered by Davis to be characteristic of the Basin ranges in particular; the King mountains, the Powell surface, the Gilbert fault blocks, and the Louderback lava caps are all represented.[2] The folded structures, truncated by later faults, were first recognized by King and evidence Laramide and Jurasside deformation. Similar relations are shown by the extension of the Gros Ventre axes of folding into the Teton Range. The Powell surface, which bevels the

[1] W. T. Thom, Jr., "The Relation of Deep-Seated Faults to the Surface Structural Features of Central Montana," *Amer. Asso, Petrol. Geol. Bull.*, Vol. VII (1913), pp. 1–13.

R. T. Chamberlin, *op. cit.*

[2] W. M. Davis, "The Peacock Range, Arizona," *Geol. Soc. Amer. Bull.*, Vol XLI (1930), pp. 293–313.

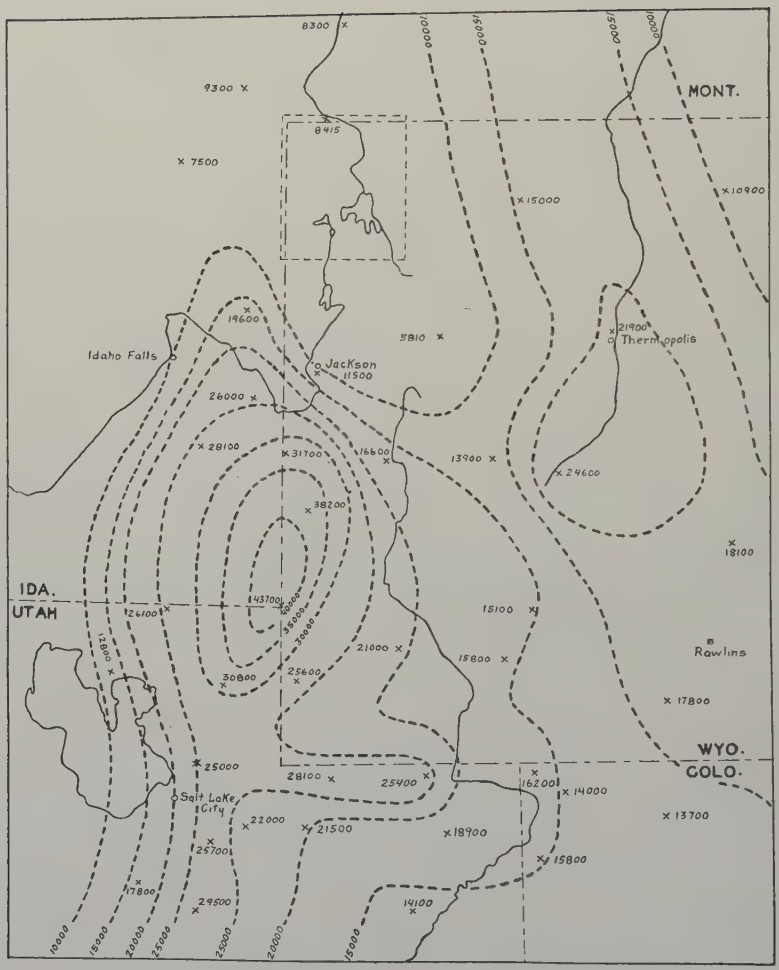

FIGURE 11.

Isopach map showing thickness of Paleozoic and Mesozoic beds in western Wyoming and adjacent areas.

older folds, is represented by the pre-volcanic surface on the Teton backslope and its cover of volcanics fulfills the requirements of the Louderback lava cap. The Gilbert fault blocks have their counterparts in the Teton Range and the smaller fault blocks in Jackson Hole (Fig. 8, B-B, D-D). These features, which have been previously discussed, show that the Tetons have had a history very similar to that of many of the Basin ranges.

Uplift of the Teton Block.

Taken as a unit the Teton Range may be regarded as a simple fault block which has been uplifted along its eastern margin and given a westward tilt, but when viewed in detail it is seen to be composed of individual units which underwent varying amounts of movement. The relative uplift of the various blocks and their direction of tilt is shown in Fig. 12. Consideration of these relations, together with other lines of evidence, seems to justify the following conclusions regarding movements within the blocks:

(1) Maximum uplift occurred in the vicinity of the high peaks and involved blocks XI and XII (Fig. 12). The superior elevation of the peaks near the center of the range is explained by the uplift of blocks XI and XII along the Buck Mountain fault. The eastward extension of the Table Mountain fault, coupled with the postulated fault in the pre-Cambrian in south Cascade Canyon, may be responsible for the higher altitude of Mount Owen and the Grand Teton.

(2) The north end of the range has been uplifted relatively higher than the southern part, since the high altitude of the crystalline rocks in block XII continues north as far as Mount Moran.

(3) North of Death Canyon tilting has been more directly to the west than it has in the area to the south where there is a notable northward component.

(4) Breaking up of the block in the southern part of the range was accompanied by a decrease in the amount of uplift, so that blocks I–IV are almost entirely within areas of sedimentary beds.

(5) Differential uplift was made possible by high-angle faults, which cross the main trend and have their maximum

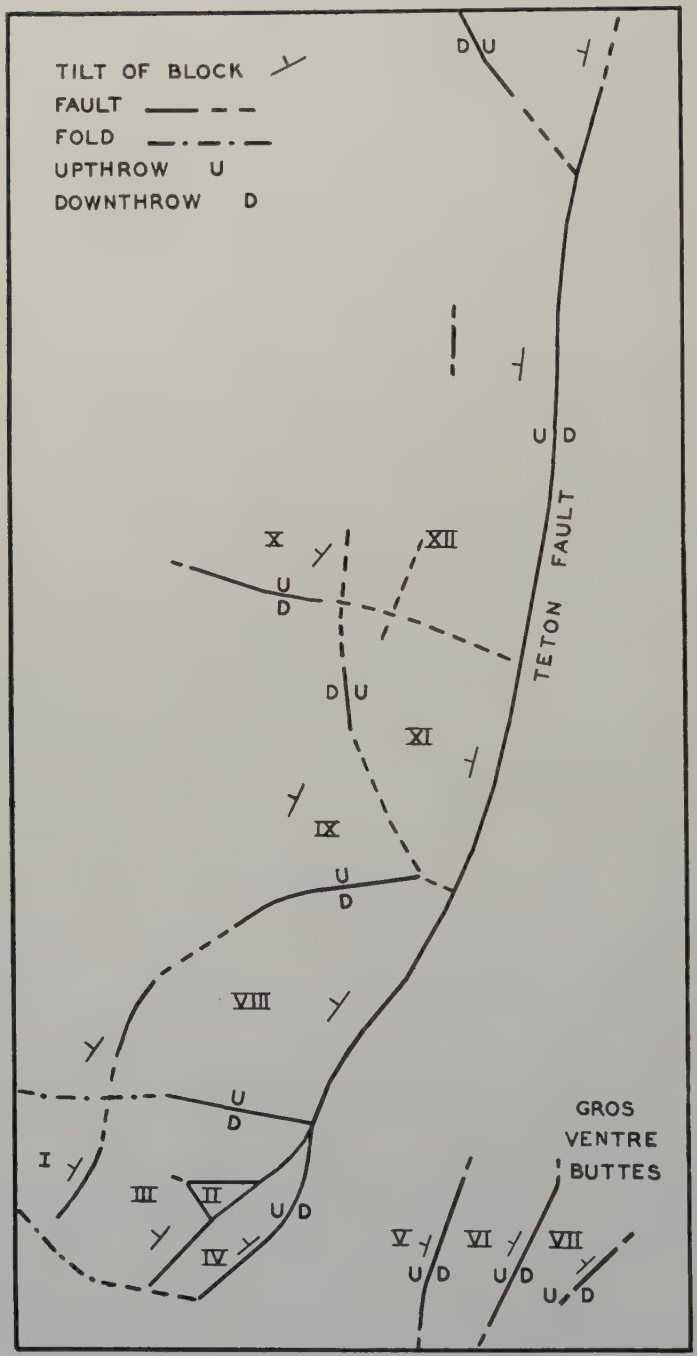

FIGURE 12.
Fault map of the Teton Range.

throw at the front of the range, and also by considerable warping. It seems probable that differential movement is to be explained by both variations in the intensity of initial uplift and by relaxational movements following the main period of faulting.

(6) The south limbs of the Taylor Mountain and Moose Creek anticlines were probably steepened at the time of block faulting.

(7) That the position of the fault along the front of the range was controlled by structures in the pre-Cambrian is suggested by the parallelism between the scarp and the strike of the crystalline rocks.

Cause of Faulting.

The cause of the faulting responsible for the formation of the Teton block presents essentially the same problem as the origin of Basin-Range structures. The various aspects of this problem are well-known and will not be reviewed. Whether the faults are normal in character and were due to tensional stresses resulting from the collapse of a dome or from magmatic activity, or whether they represent upthrusts, can not be decided from evidence within the Teton Pass area. To the writer, the upthrust idea has most appeal, and that it fits the Teton block better than any other hypothesis is suggested by the following features:

(1) The relatively high position of the pre-Cambrian rocks in the Teton Range as compared with adjoining regions to the south and west.

(2) The isolated position of the range in its relation to others of similar type. If either magmatic activity or regional warping were responsible for faulting, a series of blocks rather than a single major displacement would be anticipated.

(3) As far as can be determined, Teton faulting occurred long after the period of active volcanism in the Yellowstone region, so if magmatic activity is postulated, it must be related to the extrusion of younger lavas in the Snake River downwarp to the west.

CHAPTER VI

PHYSIOGRAPHY

TERTIARY HISTORY

Early Tertiary Events.

After the Laramide period of deformation there followed an interval of erosion during which the pre-volcanic surface was formed. In the Teton region this surface seems to have been one of low relief, as shown by the complete truncation of folded structures in the northern part of the Teton Range, but farther east the early Eocene sediments cover a surface of marked relief.[1] In Wasatch time terrestrial sediments, beginning with the Pinyon conglomerate, were deposited on the floor of Jackson Hole, probably in response to climatic changes or warping movements. Sedimentation seems to have continued with numerous interruptions until early Oligocene time, with eruptions of andesitic breccias and flows becoming most marked in late Eocene time. In the northern part of the Teton Range and adjoining areas to the north and east, the extrusion of basic volcanic material was followed by outpourings of rhyolite which probably continued into early Miocene time.

Late Tertiary Events.

The sequence of events following volcanism are by no means clear from evidence within the area, and five alternative interpretations will be considered.

According to Blackwelder, extrusion of the rhyolites was followed in middle Miocene time by diastrophic movements, which gave rise to the Teton fault block and to general elevation of adjoining regions. During the Fremont cycle of erosion, which continued throughout most of Pliocene time, the region was generally reduced to a peneplain surface which beveled resistant rocks as well as the softer Tertiary

[1] David Love, *op. cit.*, p. 26.

sediments. In the Teton region this surface was thought to have been developed on crystalline rocks in the Gros Ventre and Teton Ranges, as well as on the Tertiary deposits filling Jackson Hole, and to have completely reduced the Teton fault block. The flat summit areas at elevations of 10,300–10,800 feet in the Gros Ventre Range, and the level summit of Mt. Moran (12,694 feet) and a smaller peak (10,000 feet) north of Birch Creek in the Teton Range, were suggested as remnants of the peneplain. During Pleistocene time the record is one of denudation interrupted by smaller and more frequent uplifts, so that before the end of the epoch the weaker beds in Jackson Hole had been reduced to their present elevation and the Teton scarp uncovered and brought into sharp relief.[1] The chief objections to this interpretation rest in the absence of a summit surface in the Teton Range and in the probable younger age of block faulting.

A second alternative considered by Blackwelder was that of an Eocene peneplain which had been either warped, faulted or uplifted by regional movements into its present position. Since the Eocene deposits are now found at lower elevations than the remnants of the surface, they may be interpreted in two ways: (a) as filling of valleys excavated in the peneplain following uplift, or (b) as remnants of once widespread deposits laid down on the peneplained surface and now preserved by down-warping or downfaulting. According to this view, the east face of the Teton Range is to be interpreted as a recent fault scarp, rather than as a faultline scarp, and Jackson Hole as a depression due to downfaulting. This hypothesis was rejected by Blackwelder largely because of: the irregularity of the pre-Wasatch surface, the short interval of time available for base-leveling following the Laramide folding, the long period of erosion following development of the peneplain, and the coincidence of relief features and lithology, which indicated that the Teton Range should be regarded as a fault-line scarp.[2] In support of the theory is the evidence of considerable warping following the period of early Tertiary volcanism and

[1] Eliot Blackwelder, "Post-Cretaceous History of Western Wyoming," *op cit.*, pp. 112–17; 199–202; 213–15; 339–340.

[2] *Ibid.*, Fig. 27, p. 214.

sedimentation. Along the west side of the Hoback Range dips of over 30 degrees were measured in the Pinyon conglomerate and at the northeast corner of the range the same beds are found at elevations of over 9000 feet. Similar movements affecting the Snake River Range are evidenced by the occurrence of remnants of andesitic flows at about this elevation along the ridge of Teton Pass. That the pre-volcanic surface has had an influence on present landforms, is shown by the fact that the uniformity of the Teton backslope is largely due to the uncovering of this surface.[1]

As a third possibility it may be assumed that peneplanation followed the period of volcanism ending in the Miocene, and that the earliest erosion surface was completed prior to faulting in middle or late Pliocene time. Unless the lower backslope of the Teton Range is regarded as such a surface, there is no evidence supporting this view, either within the area or in the volcanic highlands to the north. The surface on the backslope truncates sedimentary beds and lavas and, when projected eastward, it is found to rise above the level of the high peaks near the front of the range. To this extent it fulfills the requirements of a tilted surface which has been preserved on the lower backslope, but destroyed by erosion along the front of the block. However, the writer feels that this surface is too irregular in character to be correlated with an extensive peneplain, and that it is probably the equivalent of a younger surface still preserved within the crystalline rocks near the crest of the range.

The fourth alternative is based on the assumption that faulting and uplift in the Teton region occurred sometime during the cycle in which the summit surfaces were being developed in ranges to the south and east. This interpretation would explain the absence of an equivalent surface by assuming that time had not permitted its development within the local area. If faulting took place in the Pliocene, this would coincide to a certain extent with the most generally accepted time of peneplanation within the Rocky Mountain region. On the other hand it is unlikely that there would be local deformation of such importance during a time of general crustal stability.

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[1] See p. 50.

Finally, it is possible that the mature surface now preserved in the crystalline rocks of the range may represent the summit surface of adjoining regions, and that because of the recency of Teton uplift erosion did not advance as far in the cycle as it did in ranges which had a different diastrophic history. There is little to support this view and it is negated by the probable equivalency of this surface with the surface on the backslope of the Teton Range.[1]

Although the writer prefers the concept of peneplanation preceding block faulting in late Tertiary time, in view of the lack of evidence within the Teton Pass area and the general disagreement as to the age of the summit surface in nearby regions,[2] no single interpretation will be urged.

Since the question of whether the Teton Range represents a fault scarp or a fault-line scarp hinges to a large extent upon the same issues, this question must also remain a mooted one. To Blackwelder a fault-line scarp was suggested by the following circumstances: (1) all other faults within the area are old ones, which have lost their original topographic expression; (2) the sedimentary beds which were possibly 10,000 feet thick and which were removed from the Teton block since faulting, are still preserved in the bottom of Jackson Hole; (3) the prominence of the scarp decreases to the north and south as soon as the less resistant Paleozoic and Mesozoic beds are reached; (4) the flat-bottomed part of Jackson Hole coincides with the distribution of the weakest Eocene clays and the basin narrows where Cretaceous beds appear to the south.[3] In the light of later and more detailed studies, certain of Blackwelder's statements need further qualification. The thickness of sedimentary beds eroded from the Teton block since faulting was probably slight, and certainly not 10,000 feet, because most of this material was removed by pre-volcanic erosion, which

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[1] See pp. 66–68.

[2] The summit surfaces in the Middle Rockies have a various times been assigned to every epoch in the Tertiary period. Until recently the Eocene and Pliocene were favored, but within the last few years at least two workers have favored a mid-Tertiary age.

[3] Eliot Blackwelder, "Post-Cretaceous History of Western Wyoming," *op. cit.*, pp. 214–15. Since the time of this writing (1915), Blackwelder has stated that he is now inclined to regard the Teton front as a recent fault scrap. Personal communication, 1936.

cut deep into the crystalline rocks. It seems more probable that the only material removed from the front of the block since faulting was an indeterminate amount of volcanic and pre-Cambrian rock. Regarding the original topographic expression of other faults in the region, it must be recognized that the units within the Teton block to a certain degree still express the original uplift (Fig. 12), and that minor dislocations could have been erased during the early Pleistocene cycles of erosion. It should also be noted that the character of the material underlying Jackson Hole is not known and that the Eocene deposits are really restricted to the low *upland* south of the Gros Ventre River.

The lines of evidence suggesting a recent fault scarp are: (1) the absence of a summit surface; (2) the reflection of structural units in present topography; (3) the consequent character of most drainage lines on the Teton block; (4) the probable recent age of faulting; (5) the absence of pediment features along the east front of the range. Although the early Pleistocene erosion surfaces preserved in the range indicate that at least the lower 1000 feet of the scarp was uncovered during the glacial epoch,[1] it is possible that the upper portion of the mountain front represents the eroded original scarp. In this case the range may be regarded as a composite fault scarp,[2] the lower portion representing a faultline scarp and the upper part a true fault scarp modified by erosion.

EARLY PLEISTOCENE FEATURES

Exhumed Pre-Cambrian Surface.

In the northern half of the Teton Range there are a number of tabular ridges and flat summit areas which clearly coincide with the contact between the crystalline rocks and the Flathead quartzite. In some cases angular, residual blocks of the quartzite and basal conglomerate are preserved on the ancient surface, and leave no doubts as to its origin.[3] Since this surface, where exposed at the summit of Mt.

[1] See page 72.

[2] C. A. Cotton, *Geomorphology of New Zealand.* Part I: Systematic (Wellington, N. Z., 1922), p. 172.

[3] F. M. Fryxell, personal communication.

TABLE 2

SUMMARY OF CENOZOIC EVENTS

AGE	MIDDLE WEST	WESTERN WYOMING	
		Deposition	*Erosion and Deformation*
Recent	Recent	Alluvium	Valley Cutting
Pleistocene	Late Wisconsin	Pinedale till	.....
	Peorian ?	Loess ?	Later Interglacial
	Early Wisconsin (Iowan) ?	Bull Lake till	.....
	Sangamon or Yarmouth ?	.....	Earlier Interglacial
	Illinoian or Kansan ?	Buffalo till	.....
	.....	.....	Black Rock Cycle
	.....	.....	Union Pass Cycle
Pliocene	.....	.....	Block faulting and regional uplift ?
Miocene	.....	Rhyolite ?	.....
Oligocene	.....		.....
Eocene		Andesitic eruptives Sediments Pinyon (Almy) conglomerate	Pre-volcanic surface
Paleocene	.....	.....	Laramide folding

Moran (12,694 feet) was suggested by Blackwelder as a remnant of the summit peneplain,[1] its origin is of considerable physiographic importance. The triangular flat summit north of Birch Creek (Red Mountain, 10,262 feet), which Blackwelder described as possibly equivalent to the same peneplain since it carried stream gravels,[2] has been found instead to carry residuals of the earliest glacial till (Buffalo),[3] and is probably to be correlated with a younger erosion surface. The uncovered pre-Cambrian surface is most extensively preserved east of the divide in that portion of the range between Cascade Canyon on the south and Moose Basin on the north. It is found at elevations of about 10,000 feet near the divide and rises to the east, so that on the summit of Mt. Moran it has an altitude of 12,694 feet. Uncovering of the surface by erosion probably extended over quite a long period of time and did not take place contemporaneously throughout the range. However, it seems probable that extensive areas of the pre-Cambrian had been revealed early in the Pleistocene, since the mature preglacial surface in the crystalline rocks is found at considerably lower elevations.[4] (Fig. 14.)

Mature Surface in the Pre-Cambrian.

At various points within the pre-Cambrian area there are remnants of a mature pre-glacial erosion surface which ranges in elevation from 9,000–11,500 feet. These remnants are best preserved along the divide at the heads of North and South Leigh creeks and among the high peaks near the center of uplift. Although considerably modified by glacial action there is little question but that this is a true erosion surface. Among the high peaks, mature surfaces are found as scattered patches along divides and ridges which escaped severe glaciation. These surfaces are probably best displayed within the area between Cascade and Death Canyons. In many cases they are represented by gentle, soil-covered slopes which truncate the steeply dipping crystalline rocks.

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[1] Eliot Blackwelder, "Post-Cretaceous History of Western Wyoming," *op. cit.*, p. 201.

[2] *Ibid.*, p. 214.

[3] Rudolph Edmund, personal communication.

[4] Relations of different erosion surfaces are shown in Fig. 13.

Elsewhere the soil cover has been removed and the surface modified by erosion, so that recognition must depend upon gently sloping, bare rock surfaces which truncate structure. Gravels have been discovered on this surface in the col between Symmetry Spire and Storm Point at an elevation of 9,800 feet. They contain rounded pebbles of limestone which could only have been derived from the Paleozoic beds to the west.[1] Elsewhere in western Wyoming, postmature surfaces on the harder rocks, which rise to average

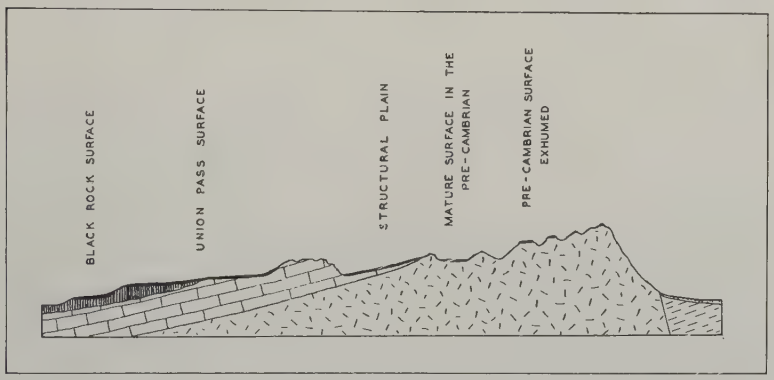

FIGURE 13.
Diagram showing erosion surfaces in the Teton Range. The figure is based on a section running east-west through Mt. St. John and the divide between Teton Canyon and South Leigh Creek.

elevations of 9,500 feet, are referred to the Union Pass cycle[2] and the surfaces in the pre-Cambrian rocks of the Tetons may represent this period of erosion.

Surface on the Backslope of the Teton Range.

When viewed from the west, the broad, gently-sloping interfluves on the Teton backslope strongly suggest a tilted peneplained surface. When examined more carefully, however, it becomes evident that the general uniformity of the backslope is due largely to the uncovering of the pre-volcanic surface, and that the younger surface modifying it is more irregular in character and in areal extent. This mature

[1] The gravels at this point were found by Richard White, the writer's field companion in the summer of 1935.

[2] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, 310–12.

surface, modifying the pre-volcanic (Eocene) plain, exists along the middle and upper portions of all the interstream areas of the backslope, and rises to elevations of about 9,500 feet. Its general appearance is that of a maturely eroded area of considerable relief, with gentle, soil-covered and grassy slopes (Fig. 15). These features are most marked in the middle portions of the divides; in the upper portions they grade into the lower slopes of the higher sedimentary peaks and ridges, and below they are in many cases indistinguishable from the terraces belonging to the younger Black Rock cycle. Their average slope is about 3 degrees,

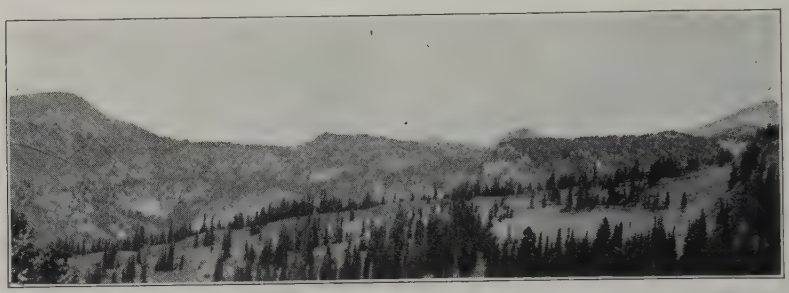

FIGURE 14.

Exhumed pre-Cambrian surface near the heads of North and South Leigh Creeks. The flat surface at two levels is a reflection of faulting and carries remnants of Cambrian strata.

if minor irregularities are ignored, and is nowhere more than 6 degrees; the average dip of the Paleozoic beds is about 10 degrees. However, it has been previously shown that the Laramide folds had been base-leveled by pre-volcanic erosion, so the extent of later truncation is indeterminate. The relation of the surface to the lavas on the lower flank of the range thus becomes an important consideration. In the northern part of the backslope, gently sloping interstream areas cross the contact between the volcanics and older rocks without any break in the ridge profile. This would be unlikely if stripping back of the volcanics had taken place under present conditions of base level, and strongly suggests erosion during an earlier cycle. This conclusion is strengthened by the finding of gravels on both volcanics and older rocks at numerous points on the surface.

The gravels for the most part are made up of chert, volcanics and quartzite of local derivation.[1]

In the northern part of the Teton Range this surface was referred by Blackwelder to the Union Pass cycle,[2] and the writer finds no serious objections to extending it to the south and correlating it with the surface preserved in the pre-Cambrian rocks to the east.

Structural Plains on the West Slope of the Teton Range.

One of the most outstanding topographic features of the upper reaches of the west slope are the extensive structural

Rudolph Edmund.

FIGURE 15.

Union Pass surface between Teton Canyon and South Leigh Creek, Teton Range. The surface at this point carries patches of Buffalo drift.

plains which are best developed on the upper beds of the Flathead quartzite and the Death Canyon member of the Gros Ventre formation (Fig. 16). Both are resistant horizons overlain by weaker shales. The massive Bighorn dolomite is also overlain by less resistant strata, but a prominent bench rather than an extensive dip plain is usually developed. Although the surfaces on the Cambrian are clearly controlled by the dip and lithology of the bedrock, certain features indicate that stripping of the overlying beds occurred prior to the initiation of the present cycle

[1] Rudolph Edmund, personal communication.

[2] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, p. 311.

of erosion. The structural plains are undissected, in part soil covered, and at least at two points carry stream gravels derived from nearby formations and from the crystalline rocks to the east.[1] Since the points at which the gravels were found are now isolated from higher pre-Cambrian rocks by deep canyons, it is clear that these surfaces were formed prior to canyon cutting in post-Buffalo time. The undissected surfaces of the plains and their abrupt termi-

FIGURE 16.

Structural plain on Cambrian limestone on the south side of North Leigh Creek, Teton Range.

nation at the edges of the present canyons can hardly be reconciled with the recent cycle of valley development.

In Jackson Hole and along the lower portion of the Teton backslope, there are surfaces which have similar relations

[1] Gravels consisting largely of pebbles less than 3 inches in diameter and composed of both sedimentary and crystalline rock were discovered by the writer and Dr. Fryxell on the divide north of Death Canyon in the summer of 1933. Similar gravels containing weathered crystalline rock were found by Edmund on the surface west of Table Mountain in the summer of 1937.

to the late Pleistocene valleys and are attributed to the Black Rock cycle of erosion.[1] It seems probable that the structural plains were also formed during this period.

Black Rock Surface.

The mature surface on which the high-level Buffalo till is found, is preserved at numerous points within the area. In Jackson Hole the pre-Buffalo topography has been described by F. M. Fryxell, who found remnants of it on the summits of the buttes rising from the floor of the basin and the benches and stream divides in the highlands to the east. The small hanging canyons and broad, shallow gulches along the front of the Teton Range, which are now located 1000 feet or more above the floor of Jackson Hole, may have been formed during the same cycle of erosion, as there is clear evidence of 800–1000 feet of erosion in post-Buffalo time.[2] In the Snake River Range there are no evidences of the surface except in the vicinity of the valley of Snake River where terraces 400 to 600 feet above the level of the river have been considered possible equivalents.[3]

On the lower backslope of the Teton Range the Black Rock surfaces are in most cases indistinguishable from those belonging to the Union Pass cycle, although notable breaks in slope separate them in a few instances. The best-preserved remnants are those near the mouths of Fox Creek, Darby Creek and Teton Canyon. Elsewhere the ridges mantled with Buffalo drift descend without interruption to the level of Teton Basin. North and south of Teton Canyon there are certain broad, shallow valley heads which hang 1000 feet or more above the bottom of the present canyon. These, together with the ancient valley slope preserved along the south wall of Darby Canyon, are possibly to be referred to the same cycle.

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[1] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, pp. 312–316.

[2] F. M. Fryxell, *Glacial Features of Jackson Hole, Wyoming*, pp. 16–25.

[3] *Ibid.*, pp. 19–20.
Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, p. 312.

Buffalo Glacial Stage.

The Buffalo drift was named and first described by Blackwelder in 1915 from occurrences along Buffalo Fork, northeast of Jackson Hole.[1] He also described other occurrences of the drift on the west slope of the Teton Range and in the northern part of Teton Basin. Later (1926) the till remnants on the East Gros Ventre Butte were noted by Alden and referred to the Buffalo stage.[2] Detailed studies of the glacial features in Jackson Hole and adjoining highlands have been made by Fryxell and should be consulted for further description of the Buffalo and succeeding drift sheets.[3]

The Buffalo drift, which once existed as an extensive cover on the Black Rock surface, is now preserved only as isolated patches on remnants of this older topography. Its present position, 500–1000 feet above present drainage, is probably the most valuable criterion for its identification. In Jackson Hole the drift consists largely of pre-glacially rounded quartzite cobbles, which average less than 8 inches in diameter and are often striated (Fig. 18). These are accompanied by a scattering of volcanic material and crystalline rocks from the Teton Range. The quartzites were probably derived from the Pinyon conglomerate where it occurs northeast of Jackson Lake in the vicinity of Pinyon Peak and Gravel Mountain.[4] On the west slope of the Teton Range a marked change in the composition of the till is to be noted in the areas north and south of Badger Creek. South of Badger Creek the till consists of material derived from the sedimentary beds and crystalline rocks of the range itself, although rounded quartzites of the Pinyon type are found occasionally. The drift material is much coarser than in Jackson Hole, boulders up to 6 feet in diameter being of common occurrence. North of Teton River the till remnants are similar to the Buffalo of Jackson Hole and consist chiefly of rounded quartzite cobbles, some volcanics

[1] *Ibid.*, pp. 328–333.
[2] W. C. Alden, "Glaciation of Yellowstone National Park and Its Environs," *Ranger Naturalists Manual of Yellowstone National Park*, 1928, p. 61.
[3] F. M. Fryxell, *Glacial Features of Jackson Hole, Wyoming*, 129 pp.
[4] *Ibid.*, pp. 28–34.

and a few subangular blocks of native quartzite. There is also a decrease in the size of constituents—only rarely are the boulders in excess of 3 feet in diameter and usually they are less than 2 feet. West of Jackpine Creek and south of

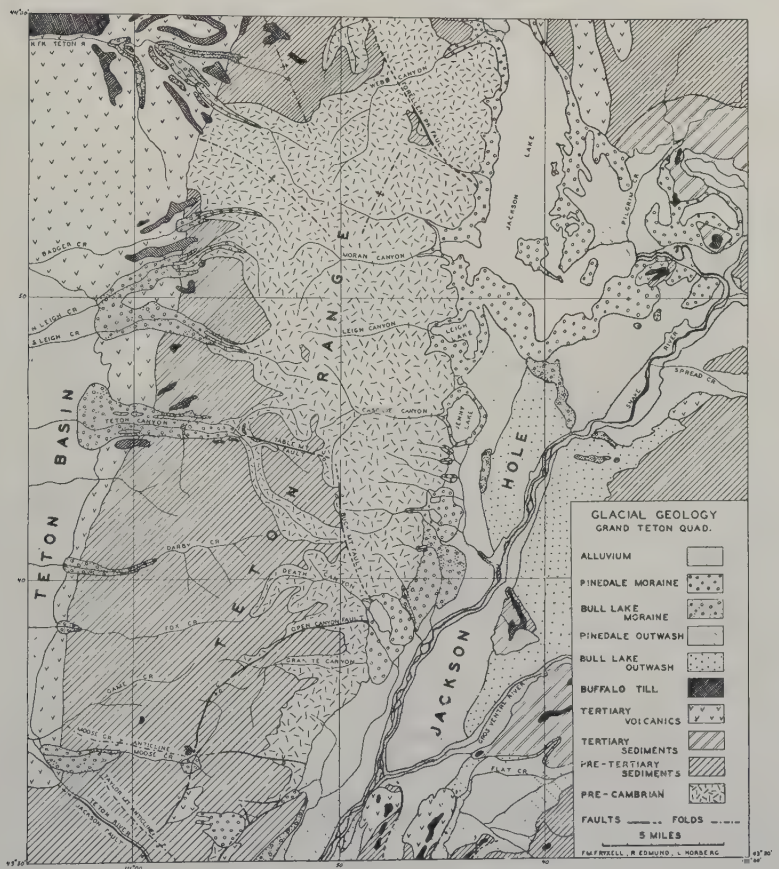


FIGURE 17.
Glacial map of the Grand Teton Quadrangle.

the middle fork of Birch Creek there is an intermixing of the two types of lithology.[1]

The occurrences of Buffalo drift in the Teton Quadrangle are shown on Fig. 17, and Fig. 46 in Blackwelder's report[2]

[1] Data on the Buffalo till north of Badger Creek has been provided by Rudolph Edmund.

[2] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, p. 330.

shows the general distribution in the area to the north and west. It is to be noted that on the west slope of the Tetons the till remnants are restricted to the interstream areas preserving the Black Rock and Union Pass surfaces, and that, although recognized as far south as Moose Canyon, the most extensive deposits are found in the northwestern part of the range.

From the distribution and composition of the drift, it is seen that the Buffalo stage was one of widespread plateau glaciation in which the ice moved southward from the Yellowstone Park plateaus into Teton Basin and Jackson Hole. At this time probably a considerable portion of the north Teton backslope was ice covered, and in the region to the northwest the ice spread out onto the plateaus at least 25 miles from the mountains.[1] In Jackson Hole the southern limit of glaciation is probably marked by the Gros Ventre Buttes, although Fryxell has suggested that the material here may be outwash instead of till.[2] During this stage valley glaciers with heads near the crest of the Teton Range doubtless merged with the ice advancing from the north, and it seems most probable that the small till remnant near Moose Creek was deposited by a valley glacier. From the evidences of its antiquity, the Buffalo drift is probably to be correlated with either the Kansan or Illinoian stage of the Mississippi Valley.

The Earlier Interglacial Stage.

This interval marks the most important period of erosion in glacial time, for it was during this stage that the outstanding topographic features of the region were given their present relief. Jackson Hole was deepened about 1000 feet, the buttes of basin were etched out into relief, and the canyons in the Teton Range were eroded to essentially their present level. On the backslope of the range there was corresponding valley development: canyons were cut to levels 500 to more than 1000 feet below the surfaces carrying Buffalo till, and the structural plains developed during an

[1] *Ibid.*, pp. 332–333.

[2] F. M. Fryxell, *Glacial Features of Jackson Hole, Wyoming*, pp. 28–29.

earlier cycle were trenched by steep-walled canyons. The valley levels formed by the end of the interglacial stage are represented by the Circle terraces of Blackwelder,[1] which mark the lower surfaces on which the Bull Lake drift was deposited. In Jackson Hole, the Circle cycle is represented by benches, terraces and spurs formed near the close of the stage and by intermediate levels corresponding to halts during the excavation of the basin. The former are best developed in the vicinity of the Gros Ventre Buttes, in the southern part of Jackson Hole, and along Fall Creek, while the intermediate surfaces are found chiefly along the northwest slope of the Gros Ventre Range and in the area underlain by Tertiary sediments between Flat Creek and the Gros Ventre River. The lower saddles on the Gros Ventre Buttes, as well as the surface on the smaller butte to the east, probably represent intermediate levels, and the old east-west valley cutting across the two main buttes suggests an old course of Flat Creek joining Snake River just to the west. On the west slope of the Teton Range the surfaces formed during the Circle cycle are represented by poorly-developed terraces near the mouths of the larger canyons. Some of these are more than 300 feet above the Pinedale outwash on the valley floor.

Bull Lake Glacial Stage.

The Bull Lake stage was named by Blackwelder from deposits occurring near the lake having that name on the north slope of the Wind River Range, and the same writer has described drift of this age in the highlands east of Jackson Hole and near the mouth of Teton Canyon, on the west slope of the Teton Range.[2] Alden briefly referred to the Bull Lake moraine south of Jackson Lake,[3] and Fryxell has described the deposits throughout the basin in detail.[4]

The Bull Lake drift occurs several hundred feet below the remnants of Buffalo till and outside the limits of Pinedale

[1] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, pp. 316–319.

[2] *Ibid.*, pp. 325–28.

[3] W. C. Alden, *op. cit.*, p. 62.

[4] F. M. Fryxell, *Glacial Features of Jackson Hole, Wyoming*, pp. 43–73.

glaciation. It is thus intermediate in position as well as in age. Topographically it is represented by well-defined moraines and outwash plains which, though frayed by erosion, still preserve youthful features. Morainal hummocks and basins are common features and the outlines of lateral and terminal moraines can be traced without difficulty, although the lakes once associated with these forms have now disappeared. The surface of the moraines is more regular and less bouldery than that of the younger Pinedale moraines. This feature is largely due to the extensive loess deposits which cover the older drifts, but are absent or very thin on the Pinedale. Except in the northern part of Jackson Hole, where materials from the north are introduced, the composition of the drift indicates local derivation.

The distribution of the Bull Lake moraines and outwash plains is shown in Figs. 9, 10, and 17. In Jackson Hole it is noteworthy that the morainal deposits are absent just outside the mouths of the canyons which were extensively glaciated during the Pinedale stage, and are present instead in the center of the basin. Farther south, along the foot of the Snake River Range, where Pinedale moraines are absent, the Bull Lake covers an extensive area and mantles the slopes up to elevations of over 7,000 feet (Fig. 19). The position of the widespread Pinedale outwash plains, which surround areas of older drift, clearly evidences the age difference between the two deposits. The Bull Lake moraines in Teton Basin are in marked contrast with those in Jackson Hole. Here Pinedale glaciation was much more feeble and the original lobate outlines of the lateral and terminal moraines are well preserved. In areal position the relations are the same. All of the major canyons of the west slope of the Teton Range were glaciated during this stage, while four escaped glaciation during the Pinedale.

The glaciers of the Bull Lake stage were dominantly of the piedmont type and were more extensively developed on the east side of the mountains than on the west. In all cases they spread beyond the limits of later Pinedale glaciers, but were always well within the area covered by Buffalo ice. Where valley glaciers existed during the Pinedale stage, there were piedmont glaciers during the Bull Lake, and

where only valley glaciers were present during Bull Lake time, Pinedale moraines are absent. In Jackson Hole there were three large piedmont glaciers, represented by the moraines south of Jackson Lake (Burned Ridge), by the remnant southeast of Jenny Lake (Timbered Island), and by the isolated patches of till south of the Gros Ventre Buttes. Of these, the one in the northern part of the basin was much the larger and is thought to have received ice from the Yellowstone Plateaus to the north and from the valley of Buffalo Fork.[1] The piedmont glacier fronting the Snake River Range on the east covered most of the southern part of Jackson Hole and extended a secondary lobe down the valley of Fall Creek as far as the mouth of Coburn Creek. With the exception of Teton and both Leigh canyons, the valleys of the west slope of the Tetons were occupied by valley glaciers. The ice from Teton Canyon deployed about a mile beyond the mountain front and deposited a well-defined lobate moraine. In the case of North and South Leigh canyons, the two valley glaciers merged to form a composite moraine on the volcanic foreland.[2]

In its degree of dissection, and also in its relation to the time of loess accumulation, the Bull Lake drift is similar to the early Wisconsin (Iowan) of the Middle West.

The Later Interglacial Stage.

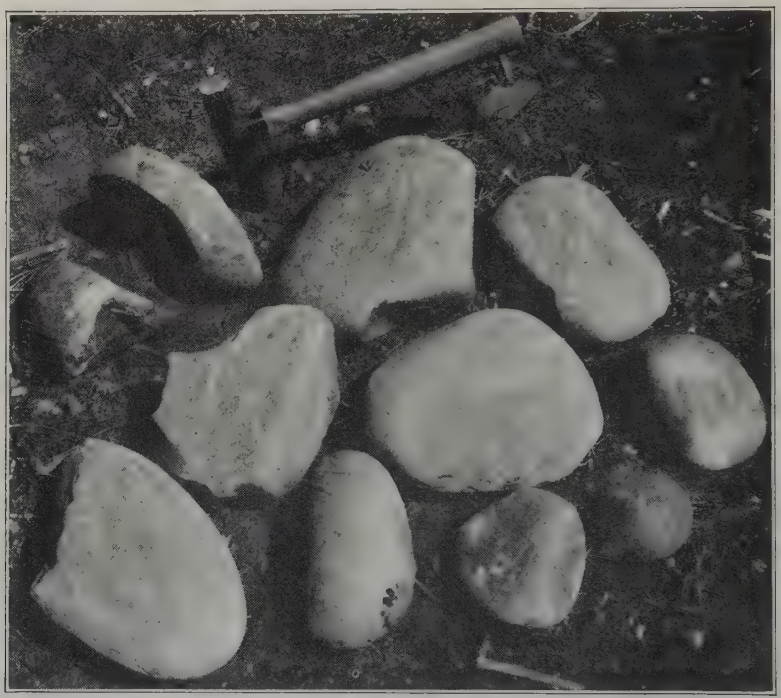
Following the Bull Lake glacial stage, the streams began the work of removing the accumulations of moraine and outwash covering the floor of the basins and choking the mouths of the canyons. By the end of the interglacial interval, the moraines had been indented, their lakes drained, and in some cases the streams had cut through the drift into bedrock. Along the major valleys, flood plains were developed and morainal deposits were cut back to the edge of the mountains. The erosional features developed during this stage are referable to the Lenore cycle of Blackwelder.[3]

[1] *Ibid.*, pp. 44–45.

[2] The moraines north of Teton Canyon were not examined by the writer, but have been mapped and studied in detail by Rudolph Edmund.

[3] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, pp. 319–321.

The loess deposits, which accumulated to depths of 15 to 20 feet on the surface of the Bull Lake till and outwash, for the most part belong to this period. This is shown by the fact that the loess on the Pinedale drift is inconsequential and that most of the dissection of Bull Lake deposits occurred after its deposition. Thick and extensive loess



F. M. Fryxell.

FIGURE 18.

Striated cobbles from Buffalo drift on the summit of Blacktail Butte. The striae have been superimposed on pre-glacial, stream-rounded cobbles.

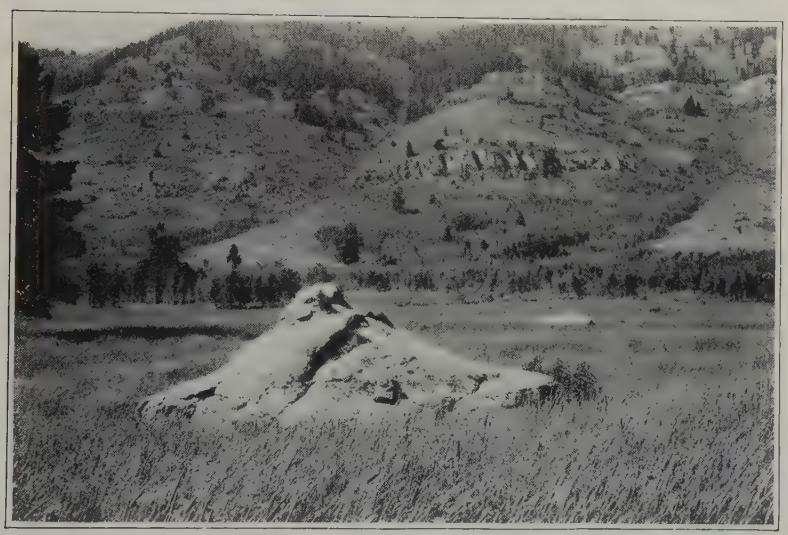
deposits are found on the Bull Lake moraines along the east front of the Snake River Range and on the volcanic foreland in the northeast part of Teton Basin.

Pinedale Glacial Stage.

The moraines of the Pinedale stage, so conspicuously developed along the east front of the Teton Range, have been

[1] F. M. Fryxell, *Glacial Features of Jackson Hole, Wyoming*, pp. 77–78.

noted by practically all geologists visiting the region since the time of the Hayden surveys (1872–1877). The Pinedale stage was named by Blackwelder from the town by that name on the southwest side of the Wind River Range, and the same writer first referred the moraines of Jenny and Taggert lakes in Jackson Hole to that stage.[1] For a thorough discussion of these features Fryxell's study should be consulted.[2]



F. M. Fryxell.

FIGURE 19.

Bull Lake moraine near Wilson, Wyoming. Weathered boulders of gneiss protrude through the loess mantling the moraine.

The Pinedale moraines are readily distinguished from those of the preceding stage by their fresh appearance and position upstream from the older moraines. They are bouldery and almost untouched by erosion and contain numerous undrained basins, as well as large morainal lakes. The beautiful piedmont lakes aligned along the foot of the Teton Range were formed by glaciers issuing from the larger

[1] Eliot Blackwelder, "Post-Cretaceous History of the Mountains of Central Western Wyoming," *op. cit.*, p. 324.

[2] F. M. Fryxell, *Glacial Features of Jackson Hole, Wyoming*, pp. 81–121.

canyons and depositing morainal barriers (Fig. 20). The outwash plains, associated with certain moraines, cover a large part of the floor of Jackson Hole and are marked by pitted surfaces and abandoned channels.

In Jackson Hole, moraines of Pinedale age are limited in their extent to the area north of Phillip's Canyon, which included the highest portion of the Teton Range. The distribution of the Pinedale deposits in the Grand Teton quadrangle, as shown in Fig. 17, clearly evidences the influence of the high summit area on the extent of glaciation. The unusually large moraine encircling Jackson Lake appears to have been formed by a large piedmont glacier fed from the northern slopes of the range, but possibly also related to a larger ice mass in the Yellowstone region.[1] On the west slope of the Tetons, Pinedale moraines are found in six of the larger canyons which head deep in the range. Strong morainal forms are largely absent and the deposits are found well within the canyons, three to six miles upstream from the outer margins of the Bull Lake moraines.

The Pinedale glaciers included cliff, valley and piedmont types, and, with the exception of the Jackson Lake lobe, were fed by névé accumulating within cirques still preserved at the heads of the canyons. The intact condition of both erosional and depositional features strongly suggests a Late Wisconsin age.

The erosional forms resulting from this stage of glaciation are outside the scope of the present study, but it should be noted that these features are even more conspicuous than the deposits themselves, and also bear witness to intensive glacial activity within the region. The spectacular alpine features for which the Tetons are justly famous are largely the result of glacial erosion during Pinedale time.

POSTGLACIAL FEATURES

The postglacial changes which have occurred in the region are unimportant as compared with those which took place in the preceding interglacial stages. In the basins, the major streams have entrenched themselves in the broad outwash plains and in a few instances have cut into recent

[3] *Ibid.*, p. 82.

F. M. Fryxell.

FIGURE 20.

Pyetate moraine encircling Bradley and Tazzert Lakes. Blackwall Butte is seen against the outwash plain beyond.

moraines; tributaries from surrounding highlands have built alluvial fans along the margins of the larger valleys. Erosion has been much more active in the mountains, especially above timber line where the bare rock surfaces and steep slopes are now being rapidly reduced by the attacks of weathering. Landslides, rock falls, extensive talus accumulations, talus glaciers and nivation features are characteristic of these higher areas. In the canyons there has been a negligible amount of downcutting, as the streams have been primarily engaged in clearing away debris from the slopes which were oversteepened by glacial erosion.

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